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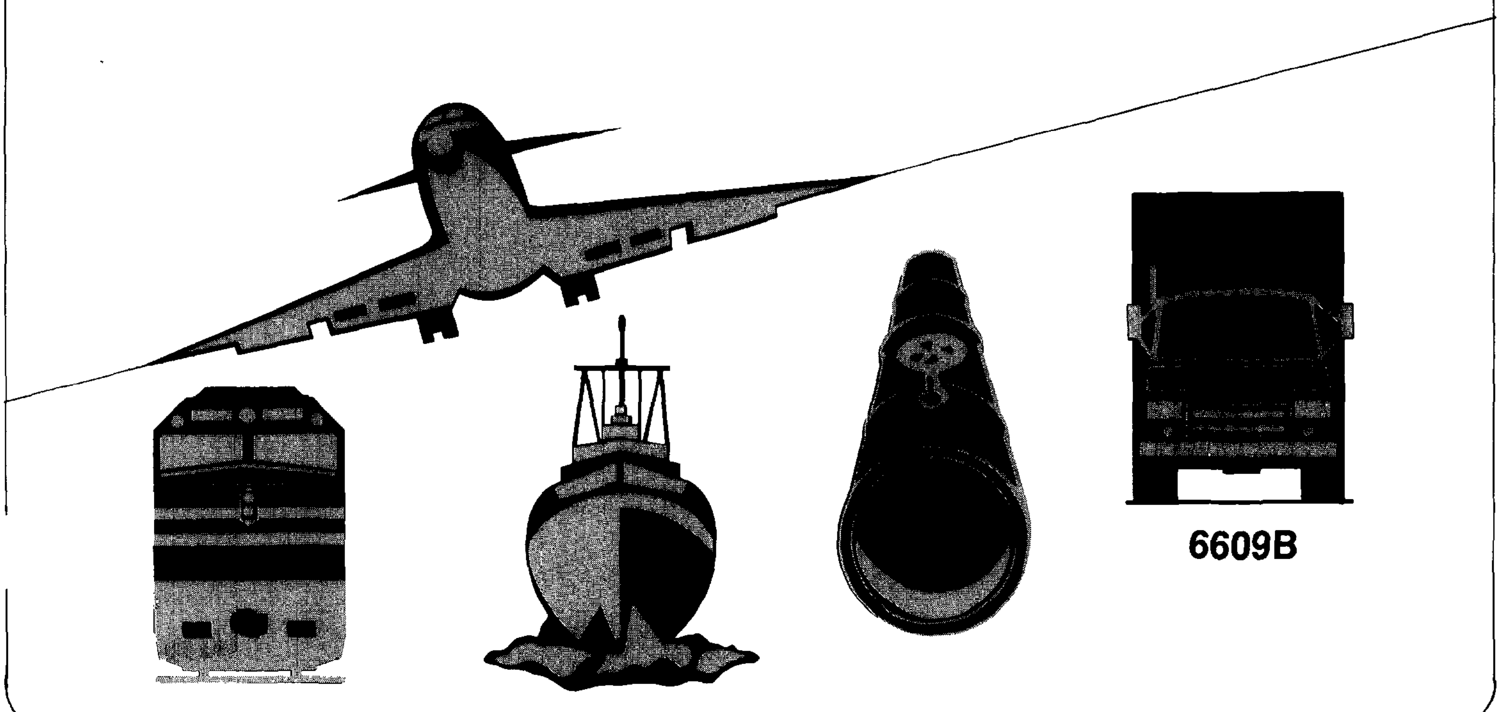
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

IN-FLIGHT LOSS OF PROPELLER BLADE
FORCED LANDING, AND COLLISION WITH TERRAIN
ATLANTIC SOUTHEAST AIRLINES, INC., FLIGHT 529
EMBRAER EMB-120RT, N256AS
CARROLLTON, GEORGIA
AUGUST 21, 1995



6609B

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EMBRAER EMB-120RT, N256AS
CARROLLTON, GEORGIA
AUGUST 21, 1995**

**Adopted: November 26, 1996
Notation 6609B**

Abstract: This report explains the accident involving Atlantic Southeast Airlines flight 529, an EMB-120RT airplane, which experienced the loss of a propeller blade and crashed during an emergency landing near Carrollton, Georgia, on August 21, 1995. Safety issues in the report focused on manufacturer engineering practices, propeller blade maintenance repair, propeller testing and inspection procedures, the relaying of emergency information by air traffic controllers, crew resource management training, and the design of crash axes carried in aircraft. Recommendations concerning these issues were made to the Federal Aviation Administration.

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EXECUTIVE SUMMARY

On August 21, 1995, about 1253 eastern daylight time, an Empresa Brasileira de Aeronautica S. A. (Embraer) EMB-120RT, N256AS, airplane operated by Atlantic Southeast Airlines Inc., (ASA) as ASE flight 529, experienced the loss of a propeller blade from the left engine propeller while climbing through 18,100 feet. The airplane then crashed during an emergency landing near Carrollton, Georgia, about 31 minutes after departing the Atlanta Hartsfield International Airport, Atlanta, Georgia. The flight was a scheduled passenger flight from Atlanta to Gulfport, Mississippi, carrying 26 passengers and a crew of 3, operating according to instrument flight rules, under the provisions of Title 14 Code of Federal Regulations Part 135. The flightcrew declared an emergency and initially attempted to return to Atlanta. The flightcrew then advised that they were unable to maintain altitude and were vectored by air traffic control toward the West Georgia Regional Airport, Carrollton, Georgia, for an emergency landing. The airplane continued its descent and was destroyed by ground impact forces and postcrash fire. The captain and four passengers sustained fatal injuries. Three other passengers died of injuries in the following 30 days. The first officer, the flight attendant, and 11 passengers sustained serious injuries, and the remaining 8 passengers sustained minor injuries.

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight fatigue fracture and separation of a propeller blade resulting in distortion of the left engine nacelle, causing excessive drag, loss of wing lift, and reduced directional control of the airplane. The fracture was caused by a fatigue crack from multiple corrosion pits that were not discovered by Hamilton Standard because of inadequate and ineffective corporate inspection and repair techniques, training, documentation, and communications.

Contributing to the accident was Hamilton Standard's and the Federal Aviation Administration's failure to require recurrent on-wing ultrasonic inspections for the affected propellers.

Contributing to the severity of the accident was the overcast cloud ceiling at the accident site.

Safety issues in the report focused on manufacturer engineering practices, propeller blade maintenance repair, propeller testing and inspection procedures, the relaying of emergency information by air traffic controllers, crew resource management training, and the design of crash axes carried in aircraft. Recommendations concerning these issues were made to the Federal Aviation Administration.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

IN-FLIGHT LOSS OF PROPELLER BLADE FORCED LANDING AND COLLISION WITH TERRAIN

ATLANTIC SOUTHEAST AIRLINES, INC., FLIGHT 529 EMBRAER EMB-120RT, N256AS, CARROLLTON, GEORGIA AUGUST 21, 1995

1. FACTUAL INFORMATION

1.1 History of Flight

On August 21, 1995, about 1253[1] eastern daylight time, an Empresa Brasileira de Aeronautica S.A. (Embraer) EMB-120RT, N256AS, airplane operated by Atlantic Southeast Airlines Inc., (ASA[2]) as ASE[3] flight 529,[4] experienced the loss of a propeller blade from the left engine propeller while climbing through 18,100 feet. The airplane then crashed during an emergency landing near Carrollton, Georgia, about 31 minutes after departing the Atlanta Hartsfield International Airport (ATL), Atlanta, Georgia. The flight was a scheduled passenger flight from ATL to Gulfport, Mississippi (GPT), carrying 26 passengers and a crew of 3, operating according to instrument flight rules (IFR), under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135. The flightcrew declared an emergency and initially attempted to return to Atlanta. The flightcrew then advised air traffic control (ATC) that they were unable to maintain altitude and were vectored toward the West Georgia Regional Airport (CTJ), Carrollton, Georgia, for an emergency landing. The airplane continued its

[1]All times are reported in eastern daylight time unless noted.

[2]The Atlantic Southeast Airlines Inc., corporate logo and airplane paint scheme are represented by the letters ASA.

[3]The air traffic control system call sign for flights of Atlantic Southeast Airlines is ASE.

[4]Because a code sharing agreement existed between ASA and Delta Air Lines, passenger flight schedules also identified the airplane as Delta flight 7529.

descent, passed through some trees, and was destroyed by impact forces with the ground and postcrash fire. The captain and four passengers sustained fatal injuries. Three other passengers died of injuries in the following 30 days. The first officer, the flight attendant, and 11 passengers sustained serious injuries,[5] and the remaining 8 passengers sustained minor injuries.

On August 21, 1995, the accident flightcrew began a 2-day trip at Macon, Georgia (MCN). They operated the accident airplane, N256AS, as flight ASE 211 from MCN to ATL. A jump seat rider, an ASA captain, reported that the flight was uneventful and that the crew appeared to be rested and in a relaxed mood during the flight.

In ATL, the captain remained in the airplane on the ground to receive the ATC clearance; the first officer deplaned and remained in the immediate area. The accident flight, ASE 529, was cleared IFR from ATL to GPT via the Atlanta 4 departure and flight planned route at flight level 240.[6] The estimated flight time was 1 hour and 26 minutes. The ASA EMB-120 load manifest prepared by the first officer recorded 26 passengers, 3 crewmembers, 724 pounds of cargo, and 2,700 pounds of fuel for departure.

ASE 529 taxied from the ramp area at 1210 and was airborne at 1223. At 1236, the first officer reported to the west departure sector of the Atlanta air route traffic control center (Atlanta Center) that they were climbing past 13,000 feet. About 1242, following several intermediate climb clearances, the controller issued a clearance to climb and maintain flight level 240, which the flightcrew acknowledged.

The flight data recorder (FDR) and the cockpit voice recorder (CVR) data[7] indicated that at 1243:25, while climbing through 18,100 feet at 160 knots indicated airspeed (KIAS), several thuds could be heard from the cockpit, and the torque on the left engine decreased to zero. The airplane then rolled to the left, pitched down, and subsequently started to descend. Immediately thereafter, the FDR shows numerous flight control inputs consistent with an attempt to counteract the flightpath deviations; however, the airplane attitude decreased to

[5]Section 1.2 contains more details regarding serious injuries.

[6]Flight level 240 represents a barometric altimeter indication of 24,000 feet.

[7]Appendix B contains the transcript of the CVR. All relevant ATC communications with ASE 529 are contained in the transcript.

about 9 degrees nose low, and the airplane began a descent rate that progressed to about 5,500 feet per minute (fpm). The captain said, "I can't hold this thing," then "help me hold it." At 1244:26, the first officer declared an emergency with Atlanta Center and stated, "we've had an engine failure." Atlanta Center cleared ASE 529 direct to the Atlanta airport.

According to data from the FDR and CVR, airspeed and descent rate changes continued and were accompanied by abrupt excursions in vertical and lateral acceleration values. At 1245:46, the CVR revealed that the first officer informed the flight attendant that they had experienced an engine failure, had declared an emergency and were returning to ATL, and he told her to brief the passengers. At 1246:13, the first officer stated, "we're going to need to keep descending, we need an airport quick and uh, roll the trucks and everything for us." The controller provided the flightcrew with heading information to CTJ. The flightcrew applied various combinations of flight control inputs and power on the right engine, partially stabilizing the airplane descent rate to between 1,000 and 2,000 fpm and the airspeed to between 153 and 175 knots indicated airspeed (KIAS).

The Atlanta Center controller lost ASE 529's transponder code from radar when the airplane descended through 4,500 feet. About 1250, he instructed the flightcrew to contact Atlanta approach control. The flightcrew contacted Atlanta approach and requested the localizer frequency and vectors for the West Georgia Regional Airport. The controller issued the localizer frequency. The flightcrew acknowledged and then requested vectors for a visual approach. The controller verified the altitude of the airplane and that the flight was in visual flight rules (VFR) conditions and said, "fly heading zero four zero...airport's at your about 10 o'clock six miles...." At 1251:47, ASE 529 acknowledged, "zero four zero ASE 529." This transmission was the last one received by the approach controller from the accident flight. After 1251:30, airspeed steadily decreased from 168 KIAS to about 120 KIAS. FDR and CVR information indicated that the landing gear and flaps remained retracted. CVR sounds indicated that the first ground impact occurred about 1252:45.

In postcrash interviews, survivors indicated that during the climbout, they heard a loud sound and felt the airplane shudder. They also indicated that two or three blades from the left propeller were wedged against the front of the

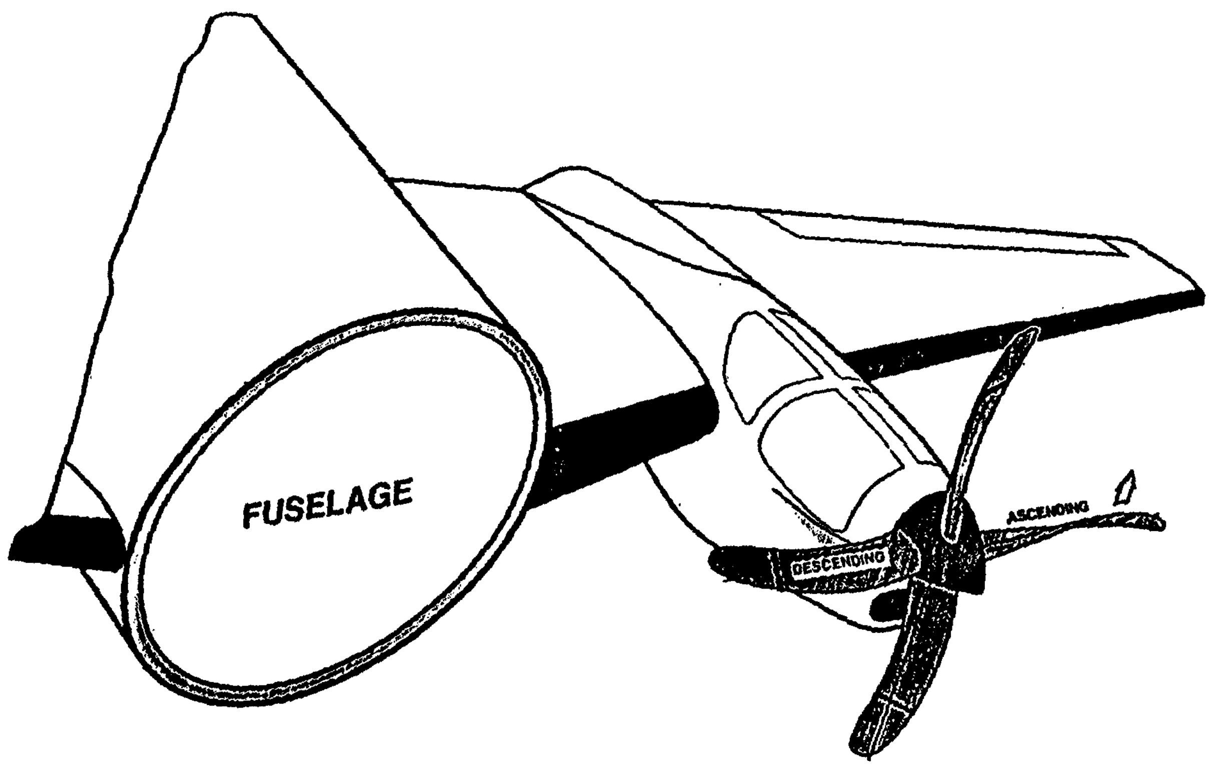

Figure 1.--Propeller installation - left wing.

wing. The flight attendant said that she looked out the left side of the aircraft and observed, "a mangled piece of machinery where the propeller and the front part of the cowling was." Other passengers observed the propeller displaced outboard from its original position on the engine (see Figure 1). The flight attendant stated that after the first officer notified her of the flight's emergency return to ATL (at 1245:46), she prepared the cabin for an emergency landing and evacuation. She stated that she had no further dialogue with the flightcrew.

Investigators found the left engine propeller assembly early in the ground debris path. The propeller hub contained three complete blades and about 1 foot of the inboard end of the fourth blade protruding from the hub. The remainder of the fourth blade was not at the accident site. (See Section 1.12 for more wreckage information.)

The accident took place in daylight visual conditions. The crash site was located at 33 degrees, 34', 50.5" north latitude and 85 degrees, 12', 51.2" west longitude. A topographical map indicated that the elevation of the site was 1,100 feet above sea level.

1.2 Injuries to Persons

Injuries	Flightcrew	Cabincrew	Passengers	Other	Total
Fatal	1	0	7	0	8
Serious	1	1	11[8]	0	13
Minor	0	0	8	0	8
None	0	0	0	0	0
Total	2	1	26	0	29

1.3 Damage to Airplane

The airplane was destroyed by the impact and postcrash fire. Its estimated value was $5,000,000.

[8]One passenger died 4 months after the accident as a result of her injuries. She sustained third-degree burns over 50 percent of her body, as well as inhalation injuries. In accordance with 49 CFR 830.2, which defines "fatal injury" as any injury that results in death within 30 days of the accident, her injuries were classified as "serious."

1.4 Other Damage

The crash site was located on 20 acres of unimproved farmland with trees, adjacent to an open field. There was environmental damage from airplane fuel and fire-fighting efforts along the wreckage path, and immediately adjacent to the wreckage.

1.5 Personnel Information

The captain, age 45, held an airline transport pilot certificate for airplane multiengine land, type rated in the EMB-120, with commercial privileges for airplane single-engine land. He held a flight instructor certificate with ratings for airplane, instrument, and multiengine. His most recent Federal Aviation Administration (FAA) first-class medical certificate was issued on April 3, 1995, with the limitation: "Holder shall wear correcting lenses for near vision while exercising the privileges of his airman certificate." The captain's overnight bag, found in the wreckage, contained an empty eyeglasses case.

The captain was employed by ASA in March 1988. Company records indicate that at the time of the accident, he had accumulated 9,876.13 total hours of flying experience, with 7,374.68 hours in the EMB-120 of which 2,186.94 hours was pilot in command. His last proficiency check was on March 3, 1995, and his most recent training, on August 7, 1995, was Line Oriented Flight Training (LOFT).

The first officer,[9] age 28, held a commercial pilot certificate with ratings for airplane, single-engine land, airplane multiengine land, and instrument-airplane. He held a flight instructor certificate with ratings for airplane, multiengine, and instrument. His most recent FAA first-class medical certificate was issued on June 15, 1995, without limitations.

The first officer was employed by ASA in April 1995. Company records indicate that at the time of the accident, he had accumulated 1,193 total hours of flying experience, with 363 hours in the EMB-120. He received his ASA first officer training in April 1995, and completed his initial operating experience on May 4, 1995.

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[9]Because of his severe injuries that included burns and inhalation damage, Safety Board investigators were unable to interview the first officer.

The flight attendant, age 37, was employed by ASA on February 8, 1993. She completed her initial training, which included emergency procedures training, on February 23, 1993. She had no prior experience as a flight attendant. Her most recent recurrent training on the EMB-120 was on January 26, 1995.

Activities of the crew in the days before the accident were routine and unremarkable. They appeared to have received normal rest.

1.6 Airplane Information

1.6.1 General

The airplane, N256AS, was an Embraer EMB-120RT "Brasilia," serial number 120122, manufactured and certificated in Brazil. The airplane was certificated in the United States in accordance with a bilateral airworthiness agreement between the FAA and the Brazilian certification authorities. The airplane was delivered to ASA on March 3, 1989.

Prior to the day of the accident, the airplane had accumulated 17,151.3 flight hours and 18,171 flight cycles. Maintenance records indicate that maintenance inspections were accomplished in accordance with ASA's Standard Practice No. 624, Airplane Maintenance Program, an FAA-approved maintenance plan.

The airplane had been assigned to ASA's Dallas-Fort Worth, Texas, hub until 1 week prior to the accident when it was transferred to ASA's Atlanta hub in preparation for a "C" check (required at 3,300-hour intervals). The inspection was scheduled to take place the coming week at the ASA maintenance facility at MCN but the accident intervened. Safety Board investigators reviewed the airplane records at MCN and found no remarkable discrepancies or minimum equipment list (MEL) items carried forward in the records.

As part of the ASA maintenance program, a line check[10] is required at 75-hour intervals. A line check was accomplished by employees of ASA's MCN maintenance facility on the night of August 20, 1995, during an overnight stop. According to ASA maintenance work cards, the line check included a specific

[10]An ASA line check for the EMB-120 airplane consists of detailed visual inspections in 14 areas to detect leaks, damage, and ensure the continuing airworthiness of all systems.

visual inspection of the left and right propellers for any evidence of oil leaks or damage; and none were noted. Maintenance records indicate that a maintenance daily inspection[11] was performed at MCN on August 21, 1995, the date of the accident, by ASA line mechanics prior to the first flight of the day. Maintenance personnel indicated that a flightcrew walk around inspection was also accomplished by the first officer prior to departing MCN. Neither of these inspections noted anything remarkable.

1.6.2 Weight and Balance

ASA dispatch records indicate that the takeoff weight of N256AS at ATL was 24,237 pounds. The maximum takeoff weight, as stated in the airplane flight manual (AFM), is 25,353 pounds. The planned landing weight was 22,637 pounds; the AFM maximum landing weight is 24,802. The takeoff percent mean aerodynamic chord (MAC) was 28.65; the AFM forward and aft center of gravity limits are 21.0 and 42.0 percent MAC respectively. The airplane was within its prescribed weight and center of gravity limitations at takeoff and at the time of the accident.

1.6.3 Propeller Design

Hamilton Standard manufactures a family of composite propeller blades, including the 14RF (the accident propeller blade), 14SF, and 6/5500/F, that are intended for use on turbopropeller commuter airplanes. The solid, forged 7075-T73 aluminum alloy spar is the main load-carrying member. The airfoil shape of the blade is formed by glass fiber-filled epoxy and foam adhesively bonded to the spar (see Figure 2). A conical hole (taper bore) is bored in the center of the spar from the inboard end to blade station 21,[12] for weight reduction and balance weight installation. The taper bore on the 14RF blade can be one of two different shaped designs: straight taper bore known as the "M" style[13]) and a

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[11]An ASA maintenance daily inspection is performed prior to the first flight of the day. It consists of external and internal visual inspections, checks of system operating pressures and fluid levels, and an operational check of radio and navigational equipment.

[12]Blade stations on the 14RF model propeller are measured in inches from a reference point 3.427 inches inboard of the blade pin platform on the inboard end of the blade.

[13]Produced from February 1986 to February 1987 through serial number 85344.

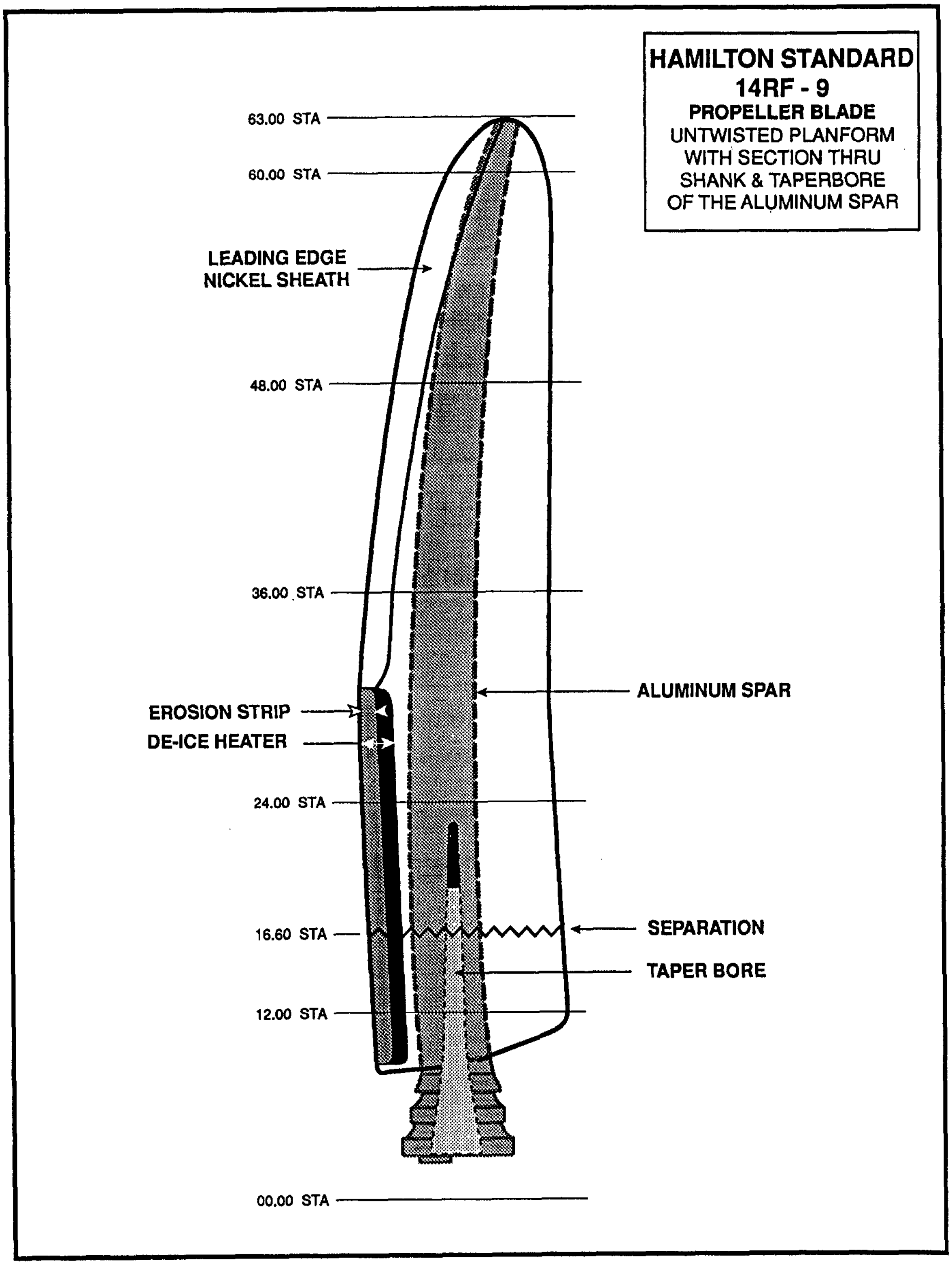

Figure 2.--Illustration of a 14RF-9 propeller blade.

bellmouth shape (known as the "N" style). Also, during very early production, the taper bore was shotpeened.[14] However, early in the production run, Hamilton Standard reviewed the production process, deemed shotpeening unnecessary, and, with FAA approval, it was discontinued. The accident blade was originally an N style blade, but it was rebalanced on customer request for ASA fleet standardization to the M style and reidentified as an M blade. The accident blade taper bore was not shotpeened during production.

The taper bore provides space for a measured amount of lead wool to be inserted for blade balancing. Until April 1994, a cork was used to retain the lead wool in the taper bore; however, it was later eliminated[15] because it was found to be a source of chlorine (and potential corrosion) in the taper bore, as well as unnecessary to retain the lead wool. The model 14RF, 14SF and 6/5500/F propellers, which vary in length from 10.5 to 13 feet, operate at a maximum of 1,200 to 1,384 rpm. As of July 1996, the 14RF, 14SF and 6/5500/F propeller assemblies were installed on 9 types of commuter aircraft, operated by 143 operators, on approximately 1,300 aircraft, for an industry total of about 15,000 blades worldwide.

According to information provided to the Safety Board in February, 1995, Hamilton Standard statistical data from field service experience indicate that blades without shotpeened taper bores are susceptible to earlier corrosion and cracking.

1.6.4 Airplane and Propeller Design Requirements on Released Blades

When the EMB-120 was certificated in the United States, the effect on safe flight of a failed or released propeller blade was addressed in FAR 25.571(e)(2), "Damage tolerance (discrete source) evaluation," which, at that time, required that the airplane be capable of successfully completing a flight during which likely structural damage occurs as a result of a propeller blade impact.

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[14]Shotpeening is a metallurgical surface treatment to improve resistance to cracking. The surface to be treated is bombarded with air-propelled glass beads or steel shot. Only the first 431 production blades were shotpeened.

[15]Use of cork was discontinued in the manufacturing process between April 1994 and November 1995. Existing corks have been removed from all model 14RF blades, and will be removed from other models pursuant to PS960A and later AD 95-05-03, which sets forth end dates for each propeller model.

Embraer petitioned the FAA on January 11, 1983, to permit type certification of the EMB-120 without compliance with that requirement. On March 22, 1983, the FAA exempted the EMB-120 from compliance with FAR 25.571(e)(2) through Grant of Exemption No. 3722, which also contained the statement that, "all practical precautions must be taken in the design of the airplane taking into account the design features of the propeller and its control system to reduce the hazard which might arise from failure of a propeller hub or blade."

In 1990, the (e)(2) requirement was eliminated from FAR 25.571. The FAA noted at that time (in the preamble to this and other regulatory changes), that service experience had shown compliance to be "impossible," and that "[a]s a result of the granting of exemptions for good cause, no manufacturer has, in fact, been required to show compliance with the current requirement." At the same time, however, the FAA promulgated FAR 25.905(d), which requires that "design precautions must be taken to minimize hazards to the airplane from a failed or released blade, including damage to structure and vital systems due to impact of a failed or released blade, and from the unbalance created by such failure." (55 Fed. Reg. 29756 at 29772, 29766, July 20, 1990.)

According to Embraer records, after initial certification of the airplane, Embraer evaluated the effects on the wing, the nacelle, and the empennage from a blade tip loss, a mid-blade loss, and a full blade loss.[16] Embraer's analysis indicated that the nacelle would not withstand the loss of a mid-blade or full blade segment.

After the accident, the FAA indicated that records from the original certification of the 14RF propeller indicate that Hamilton Standard demonstrated compliance, through testing, with the requirement of FAR 35.15 that the propeller, "not have design features that experience has shown to be hazardous or unreliable." The FAA further stated that Hamilton Standard designed, tested and demonstrated the 14RF-9 propeller blade to meet the FAR 35 requirements and it was approved as having an unlimited life when maintained in accordance with FAA-accepted Hamilton Standard maintenance instructions.

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[16]Embraer Report No. 120-DE-180, "Effect Analysis on Propeller Failures," dated September 3, 1984.

1.6.5 Airworthiness Standards for Engines and Propellers

To comply with the airworthiness requirements, the propeller manufacturer must also consider during design and must subsequently demonstrate the vibration characteristics of the propeller assembly to ensure that resonant frequencies[17] that can produce critical vibration stresses do not occur within the normal operating range of use. The applicable regulations are 14 CFR 23.907,[18] 25.907,[19] 35.37,[20] and 35.39.[21] Advisory Circular[22] (AC) 20-66 provided

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[17]The resonant frequency of any vibration is the naturally occurring frequency at which the blade will vibrate when excited. To avoid excessive vibration and overstressing of the propeller, propeller design practice requires that the propeller spend only a minimal amount of time in an rpm range that corresponds to a resonant frequency.

[18]Each propeller with metal blades or highly stressed metal components must be shown to have vibration stresses, in normal operating conditions, that do not exceed values that have been shown by the propeller manufacturer to be safe for continuous operation. This must be shown by: Measurement of stresses through direct testing of the propeller; comparison with similar installations for which these measurements have been made; or any other acceptable test method or service experience that proves the safety of the installation. Proof of safe vibration characteristics for any type of propeller, except for conventional, fixed pitch, wood propellers, must be shown where necessary.

[19]The magnitude of the propeller blade vibration stresses under any normal condition of operation must be determined by actual measurement or by comparison with similar installations from which these measurements have been made. The determined vibration stresses may not exceed values that have been shown to be safe for continuous operation.

[20]A fatigue evaluation must be made, and the fatigue limits must be determined for each metallic hub and blade and each primary load-carrying metal component of nonmetallic blades. The fatigue evaluation must include consideration of all reasonably foreseeable vibration load patterns. The fatigue limits must account for the permissible service deterioration, such as nicks, grooves, galling, bearing wear, and variations in material properties.

[21]For variable-pitch propellers. Compliance with this paragraph must be shown for a propeller of the greatest diameter for which certification is requested. Each variable-pitch propeller (the pitch setting can be changed by the flightcrew or by automatic means while the propeller is rotating) must be subjected to one of the following tests: A 100-hour test on a representative engine with the same or higher power and rotational speed and the same or more severe vibration characteristics as the engine with which the propeller is to be used. Each test must be made at the maximum continuous rotational speed and power rating of the propeller. If a takeoff rating greater than the maximum continuous rating is to be established, an additional 10-hour block test must be made at the maximum power and rotational speed for the takeoff rating. Operation of the propeller throughout the engine endurance tests is prescribed in Part 33 of this subchapter.

the propeller manufacturer an acceptable means of compliance with the CFRs relating to airplane propeller vibration.

In Chapter Two, Vibration Measurement Program, it is recommended that for multiengine installations:

> Propeller diameters to be used are tested in at least two percent or two-inch intervals throughout the diameter range to be approved and should include the maximum diameter and the minimum diameter, including cutoff repair limit.

AC 20-66 also states:

> For installations where the propeller diameter is greater than 13 feet or the engine nacelles are toed in or toed out, propeller vibration testing include complete flight and ground crosswind tests. Flight tests includes the effects of yaw, maximum and minimum aircraft gross weight at maximum and minimum airspeeds, flap settings during takeoff and landings, propeller reversing, and any other condition that would create an aerodynamic excitation of the propellers. On the ground, the aircraft is headed at different angles to the prevailing wind to determine the effects of crosswind excitation. Wind velocities typical of conditions to be encountered in service are included.

1.7 Meteorological Information

The West Georgia Regional Airport (CTJ) at Carrollton, Georgia, is about 4 miles northeast of the crash site. The airport authority owns and operates an Automated Weather Observing System-3 (AWOS-3). The CTJ AWOS-3, and similar independent systems at other airports that do not serve air carriers, are not connected through long-line transmission to the National Weather Service (NWS) or the FAA weather communication networks. The observations are available to airport users on a dedicated radio frequency. The CTJ AWOS-3 observation just after the accident was reported as follows:

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[22]An AC is an FAA document that sets forth an acceptable means to comply with provisions of Federal Aviation Regulations (FAR). An AC is intended for guidance purposes only and is not mandatory or regulatory in nature.

> Type--AWOS-3; time--1301; clouds--800 feet overcast; visibility--10 miles; temperature--76 degrees F; dew point--75 degrees F; wind--150 degrees at 6 knots; altimeter--30.08 inches Hg;

Anniston Airport (ANB), Alabama is about 32 miles west of the crash site. The reported ANB aviation weather observation just before the accident was as follows:

> Type--Record; time--1252; clouds--estimated ceiling 1,500 feet broken; visibility--5 miles; weather--haze; temperature 87 degrees F; dew point--73 degrees F; wind--050 degrees at 5 knots; altimeter--30.02 inches Hg.

The departure airport, ATL, is about 40 miles east of the crash site. The reported ATL aviation weather observation just before the accident was as follows:

> Type--Record special; time--1246; clouds--200 feet scattered measured ceiling 1,600 feet broken 3,400 feet overcast; visibility--2 miles; weather--light rain fog, temperature 73 degrees F; dew point--73 degrees F; wind--140 degrees at 3 knots; altimeter--30.08 inches Hg; remarks--surface visibility 5 miles.

The CVR transcript at 1250:15 (2 minutes and 30 seconds before impact) contained a captain's statement that, "we can get in on a visual." The FDR altitude at that time was about 3,760 feet. The CVR transcript at 1251:05 (1 minute and 40 seconds before impact) contained a captain's statement, "we can get in on a visual, just give us vectors." The FDR altitude at that time was about 2,450 feet. The ATC and CVR transcripts indicate that the first officer reported at 1251:33 (1 minute and 12 seconds before impact) "out of nineteen hundred (feet) at this time" and the captain added "we're below the clouds, tell 'm." The first officer then transmitted, "'K we're uh, VFR at this time, give us a vector to the airport."

A helicopter pilot, who arrived at the accident site about 1400, estimated scattered clouds at about 1,500 feet and a broken ceiling at around 2,500 feet. He estimated the visibility at 3.5 miles in haze.

1.8 Aids to Navigation

There were no reported or known difficulties with the navigational aids.

1.9 Communications

There were no reported or known communications equipment difficulties.

At the time of the propeller blade separation, ASE 529 was communicating with an Atlanta Center air traffic controller. Although the base of the Atlanta Center controller's airspace is 11,000 feet, the center controller continued to direct the airplane for about 7 minutes after the blade separation. At that point (1250:45), with the airplane at about 4,500 feet in altitude, changeover to Atlanta approach took place. Recorded radar information at that time indicated that the airplane was about 7 miles from CTJ. The Atlanta approach controller issued a vector toward the CTJ ILS localizer at 1250:49. Later the controller provided the localizer frequency; however, neither the AWOS frequency nor the CTJ weather conditions were provided.

Atlanta approach is responsible for flights inbound or outbound from ATL and all airports within an approximate 40-mile radius, which includes CTJ. However, the ATL approach control facility's access to the CTJ AWOS weather information is limited to commercial telephone sources. The Georgia Department of Transportation, which (as the operator of the airport) would be responsible for the costs of disseminating AWOS information via private communications networks directly to ATC, determined that the amount of air traffic at CTJ did not justify the cost of acquiring this service. This is because flightcrews destined for the smaller airports receive their AWOS weather information on the airport discrete AWOS frequency.

The closest weather report immediately available to the approach controller was the ATL Airport observation, the flight's departure point. No controller was assigned to the "assist" position. Although the manager and supervisor were nearby, they became occupied with coordinating and monitoring activities supporting the flight and did not attempt to retrieve the CTJ AWOS weather information by telephone. During the 90 seconds that the approach controller was in radio communication with the flight, the controller issued a vector toward the runway, stated the localizer frequency, confirmed the flight was in visual conditions, and issued a vector for the visual approach.

FAA ATC procedures[23] state, in part, "If you are in communication with an aircraft in distress, handle the emergency and coordinate and direct the activities of assisting facilities. Transfer this responsibility to another facility only when you feel better handling of the emergency will result."

Following their declaration of an emergency with Atlanta Center, at 1246:13 the flightcrew indicated their need to land as soon as possible and requested, "roll the trucks and everything for us." The controller then advised the flightcrew that CTJ was the closest airport and directed the aircraft to CTJ. However, the request for emergency vehicles was not passed to the fire department serving CTJ, (the Carroll County Fire Department) or to the Atlanta approach controller. Following the accident, Atlanta approach did call the Carroll County Sheriff's Office and was informed that a private citizen had already reported the airplane crash near CTJ.

1.10 Airport Information

CTJ has one asphalt surface runway, 5,001 feet by 100 feet, oriented 340/160 degrees, and the field elevation is 1,160 feet. There are two instrument approaches, an instrument landing system (ILS) localizer only (LOC) RWY 34 and a nondirectional beacon (NDB) RWY 34. Atlanta approach control is the feeder ATC agency on sector frequency 121.0 megahertz (MHz). Weather at the airport is available directly through an AWOS-3 reporting system on 118.175 MHz. The airplane crashed about 4 miles from the airport.

1.11 Flight Recorders

The airplane was equipped with an operating cockpit voice recorder (CVR) and flight data recorder (FDR). They were recovered from their installed positions in the aft portion of the airframe and appeared in good condition with only minor sooting on the cases. The CVR was a Fairchild Model A100A, S/N 57597. The recording was good and showed no evidence of loss of quality as a result of the crash.

[23]FAA Order 7110.65, Chapter 10, "Emergencies," Section 1, "General," paragraph 10-1-4, "Responsibility," applies.

The FDR was a Fairchild Digital Model F-800, S/N 04856, with 28 parameters of data. The recording was of good quality; however, the parameter for rudder pedal position indicated only small changes that did not approach normal travel. Postaccident investigation of the airframe wreckage revealed that the rudder pedal potentiometer coupler was not securely connected to the shaft of the rudder pedal potentiometer.

ASA maintenance records indicate that the rudder pedal potentiometer was installed on the accident airplane in November 1990. The most recent calibration check was performed in June 1994. At that time, no discrepancies were noted during a 3-point calibration check (neutral, full left, and full right). On June 27, 1996, the Safety Board issued two safety recommendations to address this issue (see Section 1.18.1).

1.12 Wreckage and Impact Information

The main wreckage area consisted of the cockpit, fuselage, right wing and engine, and the empennage. Portions of two of the right engine's propeller blades remained attached to the propeller hub and engine. The remaining two blades of the right engine propeller assembly were located nearby. An area of the grass leading up to and surrounding the main wreckage was burned out to a radius of about 30 feet.

The airplane came to rest at the northwest end of an 850 foot wreckage trail that was aligned on a heading of about 330 degrees magnetic. Numerous trees were sheared off prior to ground contact, consistent with a descent angle of about 20 degrees, and an increasing left-wing-down attitude of 15 to 40 degrees. Impact with the trees extended for about 360 feet, and, following the last tree impact, a debris path continued for 490 feet through an open field on slightly upsloping terrain to the main wreckage.

Prominent ground scars were observed at the beginning of the debris field (about 40 feet from the last tree impact) that were consistent with the dimensional measurement of the left wing to the fuselage. The first scars contained several pieces of the left wing. Ground scars were consistent with separation of the left wing at its root. Debris from the airplane was scattered along the wreckage path in the field. The left engine's propeller and reduction gear box (RGB) assembly were located approximately 160 feet past the tree line. The propeller hub and blade assembly contained three complete propeller blades with the inboard piece of a fourth blade protruding about 1 foot from the hub.

The Safety Board's Airplane Performance Group used its WINDFALL computer program to calculate the trajectory of the missing blade piece. The group devised a search area and alerted the local residents and authorities about the missing piece. Three weeks after the accident, the outboard piece of the blade was discovered by a farmer. It had been well hidden in some tall grass within about 100 yards of the primary search area.

The fractured blade sections were sent to the Safety Board's Materials Laboratory for detailed examination (see Section 1.16.1 for details).

1.12.1 Fuselage

The aft portion of the fuselage had separated from the forward portion in two places, near the trailing edge of the wing and also just behind the cockpit. The forward fuselage section (including the cockpit) was upright. The aft portion of the fuselage was resting on the right side and was supported by the right horizontal stabilizer. The vertical stabilizer was intact and essentially undamaged. Most of the passenger cabin that was not resting on the ground was destroyed by fire.

The right side of the forward fuselage from the radome rearward to the cockpit had very little damage. The left side of the forward fuselage below the cockpit window from the radome to just forward of the passenger/crew entry door was crushed in, aft, and up to the left side of the nose landing gear wheel well. Inward deformation was less severe near the aft portion of the crushed area. The external fuselage skin forward of the passenger/crew entry door was undamaged by fire except for an area of sooting aft and above the captain's side window.

Fire had destroyed the left side of the fuselage aft of the passenger/crew entry door. The fire damage extended to just forward of the cargo door and the entire right side of the fuselage from the leading edge of the wing to two seat rows forward of the cargo section. The upper portion of the right fuselage forward of the leading edge of the wing to the cockpit had also been destroyed by fire.

1.12.2 Wings

The major portion of the left wing, with the nacelle and engine partially attached, came to rest along the wreckage path about 125 feet in front of the cockpit. The inboard portion of the left wing leading edge, from the fuselage to the left engine nacelle, was intact. The leading edge outboard of the left engine nacelle was recovered from the debris field but was broken into several pieces. There were no cuts or gouges in the leading edge. The inboard and nacelle flaps and the inboard flap track for the outboard flap were attached. Damage to the flap tracks was consistent with the flaps being in the retracted position.

The entire right wing remained intact and attached to the fuselage. The inboard section of wing between the engine and the fuselage was destroyed by fire. There was no fire damage to the wing outboard of the engine. All flap segments appeared to be in the retracted position.

1.12.3 No. 1 (Left) Engine Nacelle

The outboard member of the front frame of the No. 1 left engine nacelle was deformed aft approximately 90 degrees and was twisted outboard slightly. There was also a semicircular flattened area in the middle of the outboard member of the front frame. The axis of the flattened area was oriented upward approximately 20 degrees from the horizontal. The forward inboard engine mount bolt had sheared in an upward and slightly outboard direction. The corresponding metal surface area of the attachment fitting was smeared in the same direction.

The engine air inlet fairing and the forward portion of the forward cowling remained attached to the propeller/RGB assembly, but they were deformed outboard. Both steel tubes connected to the forward and aft engine mounts were found separated from the terminal ends. The inboard tube was bent slightly; the outboard tube was not bent.

Five of the six hinges that secure the inboard and outboard forward cowling doors were attached, but they were bent in a direction consistent with up and aft movement of the cowling doors. The area underneath several of the hinges was damaged consistent with overtravel of the hinges. The forward, inboard hinge had separated, and the area of the inboard door where the hinge was attached was torn. The forward edge of both forward cowling doors was bent upward.

The forward inboard engine/RGB mount bolt, and forward, outboard engine/RGB mount, upper and lower rod ends of the inboard and outboard torque mount assemblies were removed and submitted to the Safety Board's Materials Laboratory for examination of all fracture surfaces. That examination revealed no indications of fatigue or other preexisting defects. The inboard engine/RGB mount and the outboard engine mount bolt were intact and remained attached to the engine and the nacelle structure, respectively. No deformation was noted on the inboard engine mount. The forward, outboard engine/RGB mount was deformed aft near the fracture location. No definitive failure directions were obtained from the upper rod ends, which had fractured near the first screw thread. Examination of the fracture surfaces of the lower rod ends revealed characteristics consistent with the fracture propagating inboard to outboard.

1.12.4 No. 2 (Right) Engine Nacelle

The No. 2 engine and RGB remained mounted to the wing. Although a fire consumed the adjacent inboard wing-to-fuselage area, damage to the No. 2 engine nacelle was not remarkable. All cowlings and fairings were found in place with little evidence of fire or soot.

1.13 Medical and Pathological Information

The Carroll County Medical Examiner determined that the seven fatally injured passengers succumbed to thermal burns and smoke inhalation. The cause of death for the captain was also reported to be thermal burns and smoke inhalation. However, in his report, the Medical Examiner indicated that blunt force trauma injuries to the face and head were "other significant conditions." This is consistent with impact-related damage on the forward left side of the fuselage. The first officer survived with burns over 80 percent of his body. Physicians indicated that as a result of his injuries, he would require extensive therapy.

Urine samples obtained post-mortem from the captain, and blood and urine samples obtained from the first officer after the accident, tested negative for alcohol and other drugs of abuse.

1.14 Fire

Based on ASA flight dispatch records, investigators estimated that about 350 gallons of fuel were on board at the time of the accident. Per normal operating practice, the fuel would have been equally distributed between the left and right side tanks. The two tanks in the left wing separated early during the impact sequence, and there was evidence of fuel spilled on vegetation along the wreckage path. The inboard tank in the right wing was found burned at the accident site, but the outboard tank was intact. Passengers did not observe fire until after the airplane came to a complete stop. They said that there was a period of about 1 minute before the outbreak of fire. The passengers described black smoke and flame consistent with what would be expected of a fuel-fed fire. Passengers reported that the fire was immediately preceded by cracking sounds and sparks from wires and cables and that the fire started in small patches and spread quickly, fully engulfing the area aft of the cockpit entrance door.

Some passengers related that they found portions of their clothing saturated with fuel, and one passenger saw "a couple of people on fire." The flight attendant and several passengers said that they had to run through flames to escape from the cabin wreckage.

The flight attendant received second degree burns to her ankles and legs. She was wearing a skirt, white blouse, hosiery, and an airline uniform vest.

1.15 Survival Aspects

The CVR revealed that the flightcrew advised the flight attendant of the planned emergency return to ATL about 7 minutes prior to impact. There were no further communications from the flightcrew to the flight attendant. The flight attendant stated that while preparing the passengers for the emergency landing, she saw tree tops, immediately returned to her seat, and shouted commands to brace for landing.

According to passengers, immediately following the loss of the propeller blade, the flight attendant checked with each passenger to make sure that they understood how to assume the brace position, and she yelled instructions to the passengers until the time of impact. Despite being seriously injured, she continued to assist passengers after the accident by moving them away from the airplane. She also extinguished flames on at least one passenger who was on fire.

The postcrash fire destroyed the passenger cabin. According to the surviving passengers, the cabin breakup started at the initial ground impact. Passengers stated that overhead storage bins in the cabin dislodged during the initial ground impact and that passenger seat structures separated and/or became deformed. According to one passenger, as the fuselage slid on its left side, several large holes were created that allowed enough daylight to appear in the cabin that provided the flight attendant and passengers visual escape cues. None of the survivors reported escaping from the cabin through the main entrance door, the overwing emergency exits, or the cabin emergency exit. They escaped through the holes in the fuselage, which were immediately behind the cockpit and aft of the wing. Passengers who were unable to escape from the wreckage succumbed to smoke inhalation.

Shortly after the airplane came to rest, the first officer attempted unsuccessfully to open the right side cockpit window, which was damaged during the impact. Thereafter, he reached behind his crew seat and retrieved a small ax with a wooden handle. He subsequently attempted to chop a hole in the side window but was only successful in chopping a hole approximately 4 inches in diameter in the center of the window through which he handed the small ax to a passenger. The passenger attempted unsuccessfully to use the ax to extricate him from the cockpit.

When a Carroll County Sheriff's deputy arrived at the scene within about 5 minutes, he saw a passenger striking the first officer's side window with the small ax,[24] which was aboard the airplane as FAA-required emergency equipment. The wooden handle separated from the ax head early in the rescue effort. About 2 minutes after the ax handle broke, the local fire department arrived and tried, unsuccessfully to break the window using full size axes. The fire department applied water to the cockpit side window. The deputy reported that during the time of the rescue, a continuous roaring sound emanated from an area behind the cockpit in which there was intense fire. In the following several minutes, the fire aft of the cockpit was controlled sufficiently to allow firefighters to enter the cabin and break through the cockpit door to rescue the first officer. The Sheriff's deputy did not observe any signs of life from the captain during the rescue sequence.

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[24]The ax had a short wooden handle about 14 inches long and resembled a hatchet. It had a single blade with a nail puller notch, and the opposite end of the blade had a shape that was similar to a hammerhead.

Postaccident inspection of the cockpit area indicated that movement of the right and left cockpit sliding windows was restricted by airframe damage consistent with impact and deformation of the windows' slide tracks. The first officer's cockpit sliding window was found to have jammed in its track in the closed position. Investigators were able to open the sliding windows with the aid of pry bars (tools not normally available to flightcrews).

The flightcrew oxygen walkaround cylinder and smoke masks were found stored, respectively, on the left and right sides of the cockpit. They did not appear to have been used. Protective breathing equipment (PBE) required in 14 CFR Part 121 airplanes was not carried (nor was it required to be) because the airplane was operated under 14 CFR Part 135.

1.16 Tests and Research

1.16.1 Laboratory Examination of the Fractured Propeller Blade

The inboard piece of the fractured blade, serial number 861398, was retained in the left engine propeller hub, which was recovered at the accident scene on August 21, 1995. The outboard piece of the blade was recovered on September 15, 1995, after it was discovered by a farmer on property about 35 miles west of the accident site adjacent to an area that had previously been searched by helicopter. Both portions of the blade were examined at the Safety Board's Materials Laboratory. The blade spar[25] was separated at blade station 16.6 (about 13.2 inches outboard of the blade pin platform). Initial visual examination revealed that a portion of the spar fracture was on a flat transverse plane and contained crack arrest positions, typical of fatigue cracking (see Figure 3). The fatigue cracking appeared to initiate from at least two adjacent locations on the taper bore surface. Below the taper bore surface, the individual cracks joined to form a single crack that propagated toward the face side[26] of the blade and progressed circumferentially around both sides of the taper bore. The extent of the fatigue cracking progressed through about 75 percent of the spar cross section. The fracture surface in areas beyond the terminus of the fatigue region contained rough features with a matte appearance, typical of an overstress separation area.

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[25]The main load-carrying member of the blade.

[26]The face side of the blade is aerodynamically similar to the bottom side of a wing.

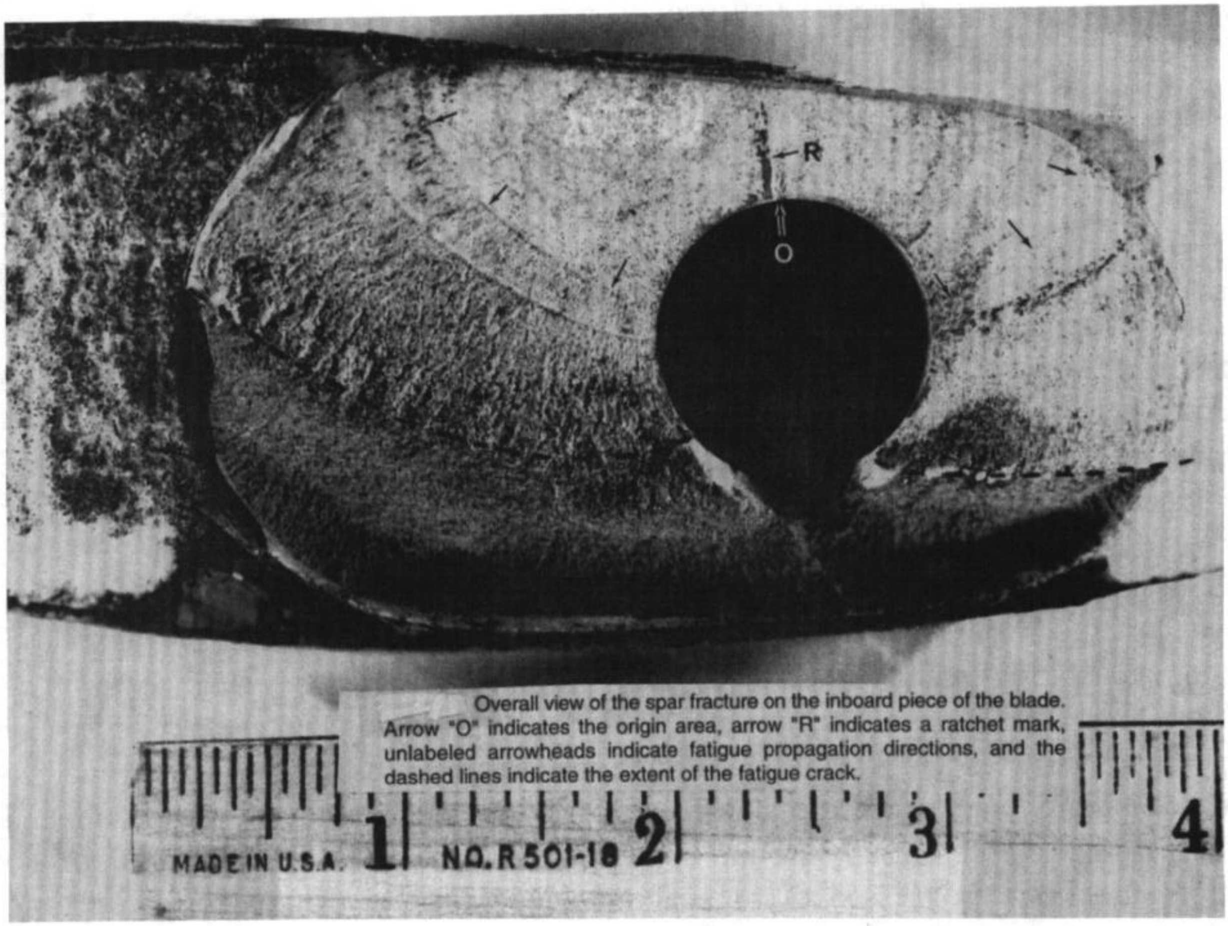

Figure 3.--Photo of the blade fracture surface.

The origin areas on both the inboard and outboard faces of the fracture were examined with a scanning electron microscope (SEM) before the faces of the fracture were cleaned. The fracture surface near the origin area on both faces of the fracture contained a layer of heavy oxide deposits that had a mud-cracked appearance. These deposits extended to a maximum depth of 0.049 inch from the taper bore surface. Their maximum circumferential width was 0.130 inch, based on the examination of the damaged outboard fracture face. X-ray energy dispersive spectroscopy (EDS) of the deposits of both faces generated similar spectra with a major peak for aluminum, a substantial peak for oxygen, and a minor peak for zinc.[27] EDS of the deposit area on the inboard fracture face also revealed the presence of chlorine.

After the fracture surface had been cleaned, additional SEM examination revealed that the fatigue cracking initiated from several corrosion pits in a line of pits in the taper bore that extended over a distance of about 0.070 inch. The maximum depth of the corrosion pitting at the fatigue origin area was measured as slightly less than 0.006 inch below the taper bore surface.

The taper bore surface, including the area adjacent to the fatigue initiation area, contained a series of nearly circumferential sanding marks. The marks extended over about 180 degrees of the circumference of the taper bore and to a maximum distance of about 1.5 inches inboard of the fracture surface. Outboard of the fracture, the sanding marks extended about 2 inches from the fracture surface.

The investigation revealed that sanding rework of the area had been accomplished using the blending repair procedures contained in PS960A.[28] The procedures required that the surface finish of the blended area should be restored to the original surface finish. Postaccident surface profilometer measurements conducted on the taper bore sanding marks indicated that the surface finish was much rougher than the manufactured surface not disturbed by the rework process.[29] Measurements also indicated that the nondisturbed surface met the manufacturing specifications.

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[27]Zinc is an alloying element in the 7075 aluminum alloy specified for the blade spar.

[28]PS960A is described in paragraph 1.16.3.

[29]The surface roughness in the blended area was measured as Ra 125, whereas the surface finish requirement of PS960A is 63 RMS, which converts to approximately Ra 50. (“Ra” denotes arithmetically averaged roughness.)

The taper bore was measured to determine the minimum thickness of the spar between the taper bore hole and the spar's face side and was found to be within the requirements of the manufacturing specifications. Measurements also indicated that about 0.002 inch of material appeared to have been removed from the taper bore surface during the sanding process.

Specimens of material cut from the fractured blade were tested for tensile strength, hardness, conductivity, and composition. All the tests indicated values that were consistent with the specified composition for 7075-T73 aluminum alloy.

1.16.2 Previous Failures of Similar Model Propellers

Prior to this accident, there were two failures of Hamilton Standard composite-type propeller blades that were found to have resulted from cracks that originated from inside the taper bore. The first event took place on March 13, 1994, on an Inter-Canadien[30] Aerospatiale-Aeritalia ATR 42 equipped with a model 14SF propeller blade. The second event occurred on March 30, 1994, on a Nordeste[31] Embraer EMB 120 equipped with a model 14RF blade. (Appendix C contains details of the fractures).

The Transportation Safety Board of Canada (TSB) conducted an investigation[32] of the Inter-Canadien event. TSP analysis indicated that forces induced from the rotation of the three remaining blades resulted in propeller imbalance and loads on the forward engine mounts that exceeded the ultimate limits. This resulted in separation of the propeller and the RGB assembly from the airplane. The RGB with the propeller hub, three complete blades, and the retained portion of the fourth blade fell onto an ice-covered lake and was recovered during the investigation. Indications were that the separated blade passed through the fuselage and caused depressurization of the cabin. There were no injuries, and the flightcrew accomplished a safe landing.

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[30]Inter-Canadien is a regional air carrier based in Montreal, Canada.

[31]Nordeste Linhas Aereas Regionals S.A. is a regional air carrier based in Salvador, Bahia, Brazil.

[32]The TSB released the results of its investigation as Aviation Occurrence Report No. A94Q0037 on February 28, 1995.

The Aircraft Accident Prevention and Investigation Center of Brazil (CENIPA) investigated the Nordeste occurrence. CENIPA did not publish a formal report; however, it provided documentation contained in a technical report by Embraer that affirmed causal findings similar to the Inter-Canadien blade separation. Embraer's report indicated that during the Nordeste event, the imbalance forces from the rotation of the three remaining blades resulted in damage to the RGB. The remaining three blades and fourth blade stub were found moved toward the feathered position (resulting in minimum aerodynamic drag); and the propeller and RGB assembly remained within the nacelle area and were partially attached to the airframe. There were no injuries, and this flightcrew also accomplished a safe landing.

Laboratory examination of the failed blades indicated the presence of chlorine-based corrosion pits in both instances. The chlorine source was traced to a bleached cork installed in the taper bore to retain the lead balance wool. These findings were corroborated by Hamilton Standard engineers and the FAA.

In addition to the Inter-Canadien and Nordeste propeller blade fractures that were related to taper bore corrosion, on August 3, 1995, about 3 weeks prior to the ASA accident, there was an in-flight loss of a Hamilton Standard Model 14RF-9 propeller blade that was not related to taper bore corrosion. The propeller was installed on a Luxair[33] EMB-120 airplane that was in the final approach to landing when the right propeller and portions of the RGB separated. Some of the separating components struck the airplane; the flightcrew accomplished a safe landing, and there were no injuries. The Belgian Civil Aviation Administration (CAA) conducted an investigation on behalf of the Ministry of Transport of Luxembourg.[34] The investigation determined that one of the four propeller blades had failed from a fatigue crack about 9 inches from the butt end of the blade. It was found that the crack began on the outer surface of the blade shank in an area of mechanical damage induced by a localized interference condition between the blade spar and the foam mold, which occurred during the manufacturing process.

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[33]Luxair is a regional air carrier based in Luxembourg City, Luxembourg.
[34]The Belgian CAA released the "Final Report of Aircraft Accident" on July 5, 1996.

1.16.3 Blade Inspection and Repair - Actions Taken by Hamilton Standard and the FAA

(See Table 1 for a timeline of significant events related to the 14RF-9 propeller.) Following the March 1994 blade failures, Hamilton Standard began an immediate program to inspect ultrasonically all model 14RF, 14SF, and 6/5500F propeller blades for evidence of cracks. Blades with rejectable ultrasonic indications were returned to Hamilton Standard. Early in the process of inspecting the returned blades, Hamilton Standard discovered that some ultrasonic indications were caused by visible mechanical damage. Although no cracks were found, the mechanical damage was in excess of what engineers thought was acceptable. Hamilton Standard reviewed the shop practices and concluded that the mechanical damage was a result of tools and techniques used during the installation and removal of balance wool lead. As a result, Hamilton Standard developed repair procedures to blend locally visible mechanical damage and eliminate ultrasonic indications that had no associated cracks. This repair was described in Hamilton Standard repair procedure PS960 (and was approved by the FAA on April 8, 1994.) PS960 specified the following steps:

1) Visually inspect the blade taper bore for evidence of mechanical damage. No unblended mechanical damage is allowed.

2) Locally blend mechanical damage to 50 times the repair depth. Repair limits are 0.010" maximum stock removal for the face area, 0.020" maximum stock removal for all other areas, including end of taper bore. When the blending is complete, no evidence of damage may remain. Reference Figure 1 (page 3) for definition of face area at any taper bore location.

3) Inspect repairs using a borescope with a 1:1 magnification to verify blending to the above requirements. Surface finish of repair area must be 63 RMS.

4) Perform an ultrasonic inspection of the blade taper bore area.

5) WARNING; CONVERSION COATING IS POISONOUS TO EYES, SKIN, AND RESPIRATORY TRACT. USE SKIN AND EYE PROTECTION. MAKE SURE THE TIME YOU USE IT IS THE

MINIMUM NECESSARY. MAKE SURE THE AREA HAS A GOOD FLOW OF AIR.

6) Apply "PS960" to the face and camber side of each blade with white stenciling ink in accordance with stenciling procedures provided in the applicable Component Maintenance Manual.

With a brush, touch up all areas repaired per the above procedure with a coating that agrees with MIL-C-5541, Class 1A. Allow to cure 24 hours.

NOTE: Alodine 600 is recommended because it is without cyanide, but Alodine 1200 or 1201, or any material which agrees with MIL-C-5541, Class 1A is satisfactory.

Soon thereafter, it was determined that the cork in the taper bore contained chlorine residue that could cause corrosion in the taper bore. As a result, PS960 was amended by PS960A to include procedures to eliminate the taper bore cork and to replace it with a sealant. PS960A was approved by the FAA on April 18, 1994.

Concurrent with the development of the PS960A repair procedure, Hamilton Standard was also developing a series of alert service bulletins (ASB) to address the problem of cracks originating from inside the taper bore in the model 14RF, 14SF, and 6/5500F blade spars. The bulletins called for a one-time, on-wing ultrasonic shear wave inspection to be performed by level II[35] Hamilton Standard employees or contractor inspection teams to detect abnormalities in the blade taper bore. Blades rejected for ultrasonic indications above specified limits found during the on-wing inspection were to be removed from service and sent to Hamilton Standard Customer Support Centers. Upon receipt of the blades,

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[35]Hamilton Standard inspectors were certified according to the American Society for Nondestructive Testing (ASNT) or the Hamilton Standard, FAA-approved equivalent. According to ASNT, an NDT Level II individual is qualified to set up and calibrate equipment, and to interpret and evaluate results with respect to applicable codes, standards, and specifications. The NDT Level II is thoroughly familiar with the scope and limitations of certain NDT methods, and guides and performs on-the-job training of trainees and NDT Level I personnel. The NDT level III individual is familiar with other NDT methods and is capable of training and examining NDT Level I and II personnel for certification in those methods.

TABLE 1

SIGNIFICANT EVENTS RELATED TO HAMILTON STANDARD 14RF/SF SERIES PROPELLERS

Previous Accident(s): Blade Separation

Date	Company	Airplane Type
3/13/94	Inter-Canadien	ATR-42
3/30/94	Nordeste	EMB-120

Inspection and Repair Action

Date	Document	Reason	Action
4/8/94 4/18/94	Hamilton Standard PS960, as revised by PS960A. (FAA approved procedure.)	Mechanical damage and chlorine deposits found in taper bores.	-Visual inspection for mechanical damage. -Blend mechanical damage. -Remove cork and replace with sealant.
4/18/94	Hamilton Standard ASB 14RF-9-61-A66	Inter-Canadien & Nordeste blade failures due to fatigue cracking	-One-time on-wing ultrasonic inspection to detect abnormalities in taper bore - If rejectable indications are found, remove from service and return to Hamilton Standard
4/27/94	Hamilton Standard Internal Memorandum	To document decision to use 960A repair to eradicate UT indications caused by peaks of shotpeen impressions	-Was interpreted as expansion of PS960A blending repair to include blades without mechanical damage.
5/2/94	AD 94-09-06		-Required one-time UT inspection for cracks in taper bore (within 45 days) in accordance with ASB 14RF-9-61-A66. - If cracks are found, replace propeller.

ASA Accident Blade History

5/19/94 ASA accident blade inspected on-wing per AD and removed from service.

6/7/94 ASA accident blade inspected at Hamilton Standard, no visible faults found, blend repaired per PS960A.

Inspection and Repair Action (Continued)

Date	Document	Reason	Action
8/29/94	Hamilton Standard ASB 14RF-9-61-A69 (Revised10/5/94)	Continuing airworthiness	-Repeat ultrasonic insp. every 1,250 cycles for specified unpeened blades, or do improved visual inspection per Safety Board 14RF-9-61-A70, or return to Hamilton Standard. - In all cases, return rejected blades to Hamilton Standard -Remove cork (if still installed). - ASA blade exempted.
8/29/94	Hamilton Standard SB 14RF-9-61-A70	Continuing airworthiness	-(For unpeened blades only) Improved taper bore visual inspection with borescope photo and mold transfer. - If pits found, remove from service or return to repair facility.
9/1/94	Component Maintenance Manual (CMM) No. 61-13-04	Detect corrosion, if none then repair. Eliminates PS960A	-Improved taper bore cleaning & visual inspection (cracks, pits, and mechanical damage) and FPI. - Shotpeen.
3/ 23/95	AD 95-05-03		-Required SB 14RF-9-61-A69 Rev 1, and SB 14RF-9-61-70 (by 12/31/97) and provided terminating action to repetitive inspection.

Accident(s): Blade Separation

Date	Company	Airplane Type
8/3/95	Luxair	EMB-120
8/21/95	ASA	EMB-120

Further Inspection and Repair Action

Date	Document	Reason	Action
8/25/95	NTSB recommendations	ASA Accident	Recommended re-inspection of reworked blades; vibration and loads survey; review of requirements for shotpeened taper bores.
8/25/95	TAD 95-18-51	ASA Accident and NTSB recommendations	Required re-inspection of reworked blades.
9/30/95	14RF-9-61-86, Rev 4,11/9/95	LUXAIR blade shank failure due to fatigue cracking	Shank on-wing ultrasonic inspection, for "N" blades
11/9/95	14RF-9-61-A90 ASB	same as above	Shank off-wing ultrasonic inspection, for "M" blades
11/16/95	AD 95-24-09		-Require SB 14RF-9-61-A86 Rev 4 or SB 14RF-9-61-A90.
12/15/95	14RF-9-61-A91 ASB	Revised fracture mechanics info. and risk assessment of blade and shank fatigue cracks.	-New off-wing ultrasonic insp., lead removed, each 500 cycles.
12/18/95	14RF-9-61-A95 ASB Rev 1, 12/18/95	same as above	-New on-wing ultrasonic insp., with balance lead.
1/19/96	AD 96-01-01		-Require ASB 14RF-9-61-A91 or ASB 14RF-9-61-A95.

Terminating Action

Date	Document	Reason	Action
3/6/96	14RF-9-61-A94 ASB	terminate recurrent ultrasonic inspections.	-Repair taper bore, rework to like new.
4/24/96	AD 96-08-02		-Require ASB 14RF-9-61-A94 taper bore repair by 8/31/96.

Hamilton Standard performed a borescope inspection and initiated the repair process, if warranted. The FAA mandated the inspection described in the ASBs by AD 94-09-06, effective on May 2, 1994. The AD required that blades with ultrasonic indications above 50 percent be removed from service. A rejectable ultrasonic indication was found on the accident blade, and it was removed from service on May 19, 1994. The accident blade was one of 490 rejected blades that were sent to Hamilton Standard for further evaluation and possible repair.

Hamilton Standard customized inspection and repair instructions set forth in a shop traveler form (Rock Hill Flow Traveler - Form Number RH243)[36] were used to define the taper bore inspection and repair actions for blades rejected as a result of the field on-wing ultrasonic inspections. The shop traveler form required that the taper bores of the returned blades be ultrasonically inspected again to verify the unacceptable rejectable indication. The taper bores of the blades were then to be cleaned and borescope inspected for evidence of cracks, corrosion, pits, and other flaws. None of the returned blades were discovered to be cracked. Corrosion was identified in approximately 13 percent of the blades; these blades were set aside for further analysis by Hamilton Standard engineering. Some of these blades were subsequently cut up or were otherwise destructively tested; others were used to develop further testing and repair processes. None of the blades with confirmed corrosion were returned to service.

After PS960A and the alert service bulletins were issued, Hamilton Standard discovered that a small percentage of the returned blades with ultrasonic indications did not have observable corrosion, mechanical damage, or cracks in the taper bore. All such blades identified at that time had shotpeened taper bores. Hamilton Standard determined that the roughness inherent in shotpeened surfaces could in some cases also generate a rejectable ultrasonic indication. According to Hamilton Standard engineering managers, as a measure to further reduce the number of apparently unsubstantiated ultrasonic indications and to return these blades to service, Hamilton Standard engineering personnel decided that the procedures set forth in PS960A for blending areas of mechanical damage could also be used to blend the area surrounding the ultrasonic indication inside the taper bore of shotpeened blades, even though there was no associated mechanical damage. This decision to extend the applicability of PS960A was discussed and

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[36]The shop traveler form that was in use at the time the accident blade was inspected and approved by the engineering manager at Rock Hill on May 13, 1994 (approximately 1 month before the accident blade was received there).

authorized in conference calls that included engineering managers of the three Customer Service Centers and Hamilton Standard engineering. It was implemented without the knowledge or approval of the FAA or the DER.

According to Hamilton Standard management, the authorization to use PS960A in this manner was confirmed through an internal memorandum, dated April 27, 1994, from the Manager of Operations Engineering to the three Customer Service Center engineering managers, stating:

> Subject: Blade U. T. [ultrasonic] Inspection
>
> Per direction from [the head of Project Engineering] you should handle blades returned from the field as a result of U.T. inspection as follows:
>
> 1) Perform a U. T. inspection. Record results on the ASB form except that this form should have the [applicable location] written at the top of the form. Forward the form to HSD Service via FAX.
>
> 2) Rework blade per PS960A. Perform a U.T. inspection and record the results on the modified form as described in para. (1).
>
> 3) Ship acceptable blades. Hold rejected blades until further notice.

In a letter to the Safety Board dated March 5, 1996, Hamilton Standard indicated that the intent of this memo was to document the decision to use PS960A "to eradicate false ultrasonic positives being caused only by superficial irregularities," specifically, to "remove tool marks or the peaks of shot peen impressions."

On August 29, 1994, Hamilton Standard issued an additional series of ASBs and SBs for unshotpeened blades in the 14RF, 14SF, and 6/5500/F series with procedures for repeating the on-wing ultrasonic inspection every 1,250 cycles or, in the alternative, accomplishing a borescope inspection for pits. Rejected blades were to be returned to Hamilton Standard for inspection (including FPI) and repair according to the new maintenance procedure[37] in the Component Maintenance Manual[38] (CMM), which superseded the procedures in PS960A. The 1,250 cycle interval was based on the minimum detectable flaw using the ultrasonic inspection technique and the operating time to failure of the Nordeste and Inter-Canadien blades.

Shortly after these ASBs were issued, the FAA issued AD 95-05-03, effective on March 23, 1995, referencing the Hamilton Standard SBs and ASBs and requiring that blades be ultrasonically inspected at an interval of 1,250 cycles or, alternatively, that a borescope inspection of the taper bore be performed. The AD provided appropriate ASB/SB references. If the borescope inspection found no corrosion pits in the taper bore, the blade could be returned to service. AD 95-05-03 also contained a provision that a return to service following the results of a satisfactory borescope inspection constituted terminating action to the requirement for recurrent ultrasonic inspections every 1,250 cycles.

Following this accident, the Safety Board made several urgent recommendations resulting in additional ADs. (See Sections 1.18.1) Other postaccident actions taken by Hamilton Standard and the FAA are discussed in Section 1.18.2.

1.16.4 The Failed Propeller, Information, and Service History

The fractured propeller blade from N256AS was model 14RF-9, part number RFC11M1-6A, serial number 861398, manufactured with an unshotpeened taper bore in 1989 by the Hamilton Standard Division, United Technologies Corporation, Windsor Locks, Connecticut. The 14RF-9 model blade is certificated only for the EMB-120 airplane.

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[37]Repair 4-25 in the CMM required the removal of the bore plug, cork (if installed), and lead wool, followed by a cleaning, white light borescope and FPI inspections. For unpeened blades: If a blade had damage less than 0.005 inch, with no previous blending per PS960A, then the blade was shotpeened, balanced and marked +A. If the blade had damage less than 0.005 inch, but it was previously blended per PS960A, then the blade was shotpeened, balanced and marked +B. If the damage was greater than 0.005 inch, but less than 0.020 inch (0.010 inch on the blade face), then the blade was reamed, shotpeened, balanced and also marked +B. If the damage was greater than 0.020 inch (0.010 on the blade face), then the blade was reamed, balanced and marked +C. The process was similar for shotpeened blades.

[38]The CMM is the FAA-approved maintenance manual that contains instructions for continued airworthiness of Hamilton Standard propellers.

The fractured blade had accumulated a total of 14,728 operating hours and 5,182 hours since overhaul. The overhaul was accomplished by Hamilton Standard customer service technicians at East Windsor on April 7, 1993. At that time, the blade had accumulated 9,546 hours.[39] Records indicated that only routine maintenance actions were necessary at the time of overhaul.

On April 20, 1993, upon return to ASA from overhaul, the blade was installed on an airplane (not the accident airplane) where it remained until May 19, 1994. On that day, the blade received an on-wing ultrasonic inspection of the taper bore by a Hamilton Standard contract inspector in accordance with AD 94-09-06. The blade was rejected for a 60-percent, full-scale height[40] ultrasonic indication.

The blade was removed from service and returned to Hamilton Standard facilities at East Windsor, Connecticut. It was subsequently shipped to Hamilton Standard's Customer Support Center at Rock Hill, South Carolina, for inspection and repair.

According to the shop traveler form for the accident blade, an ultrasonic inspection of the accident blade on June 7, 1994, confirmed the rejectable indication, with a reading of 52 percent full-scale height. Following this ultrasonic inspection, the lead wool was mechanically removed from the taper bore and the hole was examined with a white-light borescope for evidence of corrosion, pits, or cracks. In the space provided on the shop traveler form for the "results" of this inspection, the technician recorded, "No visible fa[u]lts found, blend rejected area."

The shop traveler form reflects that he then blend-repaired[41] the taper bore "damage" with aluminum oxide sanding tools, using the procedures of PS960A. The technician, who was not an FAA-certificated mechanic, stated that

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[39]The inspection limit for 14RF-9 propeller blades is 9,500 hours. ASA had FAA approval to fly in excess of the required inspection time by as many as 500 hours.

[40]Pursuant to criteria set forth in Hamilton Standard ASB 14RF-9-A66 (incorporated by reference in AD 94-09-06), indications of 50 percent full-scale height and above, as viewed on a cathode ray tube screen, were rejectable. Indications of 40 to 50 percent were "reportable" on the inspection record but were not cause to reject the blade.

[41]Blending in this context means grinding or sanding the surface to remove a small amount of material containing an imperfection and then restoring the surface finish to a condition equal to the surrounding area.

he was permitted to perform and sign off the work that he was qualified to perform. The technician, as an employee of Hamilton Standard's Rock Hill blade repair facility, which is an FAA-certificated repair station under 14 CFR Part 145, is not required to be a certificated mechanic to work on the propeller blades. In the shop traveler form for the accident blade, the instructions to blend the taper bore also specify that the surface finish should be 63 RMS. The block on the form was initialed and dated by the technician, but an adjacent block that would have signified a second inspection by a repairman[42] was blank. Although the shop traveler form for the ultrasonic inspection after the blending on the accident blade showed that there were no reportable or rejectable indications, the shop traveler form did not show that the blade had received a final inspection after the work was completed. However, Hamilton Standard provided ASA with an FAA Form 8130-3, Airworthiness Approval Tag, indicating that the PS960A repair had been completed.

Subsequent examination by the Safety Board indicated that about 0.002 inch of material was removed from the taper bore. The shop traveler form indicates that the blade passed a postrepair ultrasonic inspection.[43] Because no defects were found during the June 7, 1994, borescope inspection, and the blade was marked with "PS960A" (indicating accomplishment of the repair), the blade was exempt from the requirements of AD 95-05-03 (effective on March 23, 1995) for recurrent taper bore ultrasonic inspections and enhanced borescope inspection.

Investigators attempted to establish how the decision was made to blend the area of the unacceptable indication in the taper bore of the accident blade, even though there was no visible mechanical damage and PS960A did not explicitly require or authorize blending of a blade taper bore that was free of visible mechanical damage. During an interview with the technician who performed the taper bore repair, he stated that he had been told that the shotpeening of the taper bore could cause "false" ultrasonic indications. Further, he stated that he understood, based on his training in the repair by the Rock Hill

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[42]A repairman, as defined in 14 CFR, Parts 65.101 and 65.103, is recommended for certification by the repair station and is then certificated by the FAA. He must have at least 18 months of experience on the specific task, have completed specialized training, and may supervise maintenance of aircraft components by the repair station.

[43]The shop traveler form indicated that a blade that "failed" the postrepair, ultrasonic inspection could be reblended. If the blade "failed" the ultrasonic inspection after the second attempt to blend the rejected area, it was to be sent to Hamilton Standard's Windsor Locks facility.

facility Engineering Manager, that it was acceptable to use the PS960A process to blend out unexplained ultrasonic indications for blades with unshotpeened taper bores, as well as those with shotpeened taper bores. He said that he recognized the difference in surface finish between shotpeened and unshotpeened blades. He also stated that if he came across something that he did not understand or recognize, he would not hesitate to seek assistance from the facility Engineering Manager. The technician further stated that he had blended about 10 propeller blades without shotpeened taper bores that had ultrasonic indications but no visible damage. During an interview on October 19, 1995, the Rock Hill Engineering Manager stated that the April 27, 1994, memorandum covered both shotpeened and unshotpeened blades. However (as already noted in Section 1.16.3), in a letter to the Safety Board dated March 5, 1996, Hamilton Standard indicated that the memorandum was intended to document the authorization to use the PS960A blend repair to "remove tool marks or the peaks of shot peen impressions." The letter further stated that "there was no discussion of how to handle blades that had not been shot peened."

After the PS960A blending repair, the accident blade was rebalanced and the taper bore was sealed with protective material. It was also determined that some additional repair was necessary to the composite surface features of the blade. The blade was returned to Hamilton Standard's East Windsor, Connecticut, facility to complete that work. The blade was shipped back to ASA on August 30, 1994, and was reinstalled on the left propeller assembly of the accident airplane on September 30, 1994. It remained there until the accident. At the time of the accident, the blade had accumulated 2,398.5 hours and 2,425 cycles since the Hamilton Standard repair at Rock Hill.

1.16.5 Results of 14RF-9/EMB-120 Stress Survey

To reduce cabin noise during ground operation, the EMB-120 aircraft was certificated with model 14RF-9 propeller assembly designed to rotate at a relatively low ground idle revolutions per minute (rpm), between 50 and 65 percent. To operate successfully in the 50 to 65 percent rpm range without overstressing the propeller, the design had to avoid the coincidence of any blade resonant frequencies[44] with any excitation frequencies.[45] To accomplish this, the

[44]The resonant frequency of any vibration is the naturally occurring frequency at which the blade will vibrate when excited. To avoid excessive vibration and overstressing of the

upper rpm limit of 65 percent for ground operation was set below the resonant frequency of the first flat-wise mode of vibration[46] of the 14RF-9 blade of approximately 70 percent rpm. Although all 14RF blades have a resonant frequency at approximately 70 percent rpm, because of small differences in blade construction, there is some variation in the exact resonant frequency from blade to blade.[47] The exact resonant frequency of the accident blade could not be determined because it had separated and was damaged.

The Hamilton Standard 14RF-9 blade for the EMB-120 was designed so that its first flat-wise resonant frequency would not coincide with the 2P[48] excitation frequency during ground operation. However, the coincidence or close proximity of the ground rotational speed and the first flat-wise resonant frequency can place the propeller in a resonant condition and results in undesirable vibratory stress. (See Figure 4 for an illustration of the vibratory modes of the 14RF-9 propeller.)

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propeller, propeller design practice requires that the propeller spend only a minimal amount of time in an rpm range that corresponds to a resonant frequency.

[45]Excitation frequencies are created by aerodynamic loads that act on a propeller. Some aerodynamic loads on a propeller are cyclical. The frequency of these cyclical loads are multiples of propeller rpm. The frequency of the first cyclical aerodynamic load (1P) is equal to propeller rpm; that is, one cycle per revolution.

[46]The first flat-wise mode of vibration is the lowest frequency vibration. (There are multiple orders of vibration, and each has an associated frequency called a resonant or natural frequency.)

[47]A resonant frequency of a propeller blade is a function of the blade's rigidity, mass distribution and, to some extent, retention stiffness.

[48]The frequency of the second aerodynamic load (2P) acts on all propeller blades twice per revolution because the blade senses the wing leading edge as it rotates past it. The 2P excitation frequency is always present but is most pronounced during ground operation in a tailwind or quartering tailwind condition.

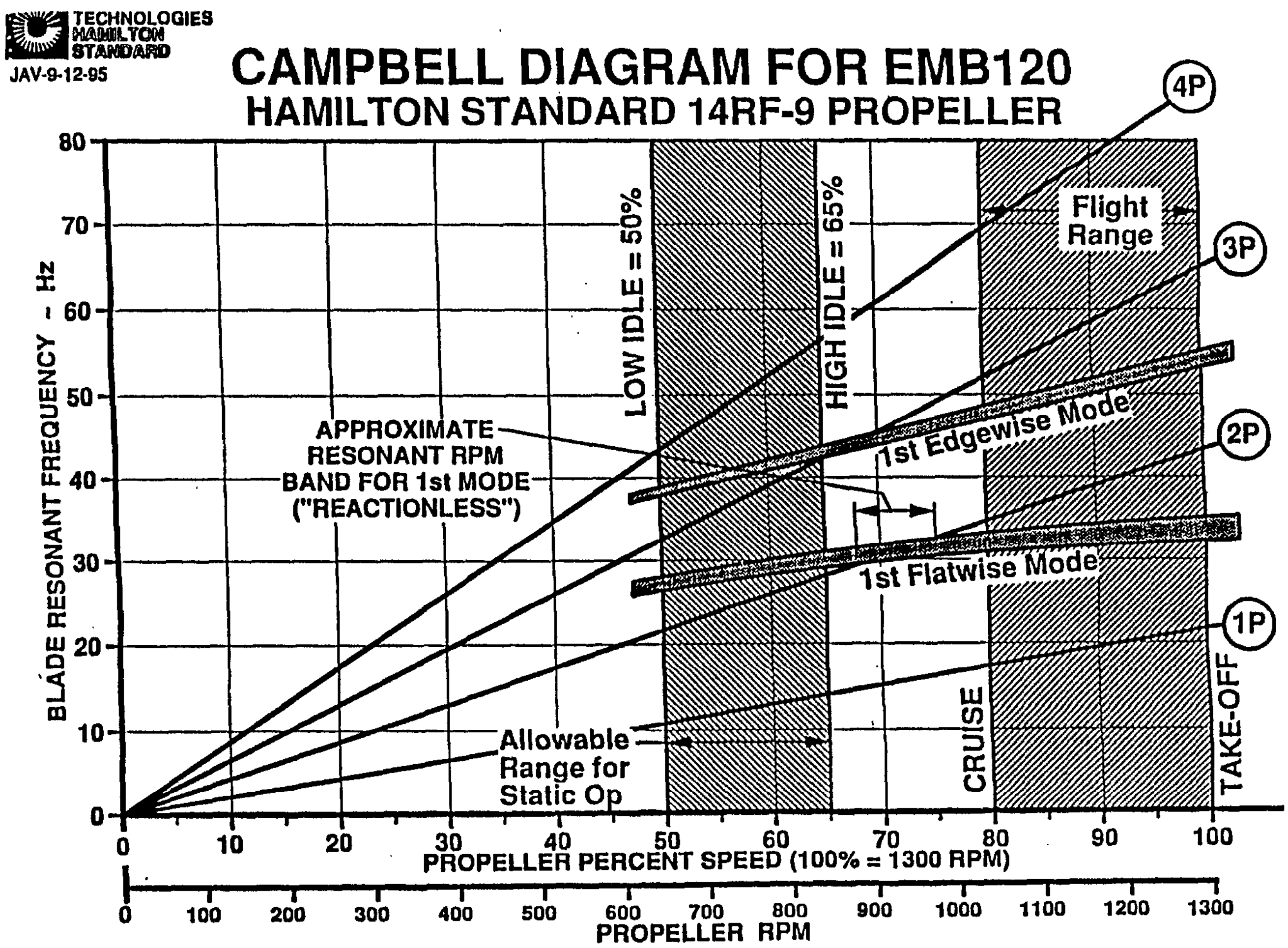

Figure 4.--Vibratory modes of the 14RF-9 propeller.

When the first flat-wise vibration frequency and the 2P excitation frequency coincide, a four-bladed propeller, such as the 14RF-9, vibrates in the reactionless[49] mode. The reactionless mode of vibration is characterized as when two blades of a four-bladed, rotating propeller, 180 degrees apart, reach a negative stress peak at the same time that the other two blades reach their positive stress peak. This type of propeller vibration is called reactionless because the bending loads of the four blades are canceled at the propeller hub which consequently transmits little or no vibratory loading to the propeller mounting structure.

As originally certificated, the EMB-120 Airplane Flight Manual, Maintenance Manual, and a cockpit placard stated that propeller rpm (Np)[50] above 65 percent should be avoided during ground operations with the aircraft stationary, and with rear quartering winds in excess of 10 knots, except for short duration transitions.

The 1983 and 1985 certification testing of the EMB 120 with the model 14RF propeller was accomplished using an instrumented, new propeller blade. The original stress surveys, which included flight and ground[51] tests, and an additional ground test following the ASA accident, revealed that the resonant frequency of the first flat-wise mode varied from approximately 70 percent to 76 percent. Because the actual resonant frequency of a propeller must be determined during ground testing, and because propeller assemblies are not measured

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[49]The Safety Board investigated another accident on April 19, 1993, in Zwingle, Iowa, in which a Mitsubishi MU-2B-60 airplane experienced an in-flight loss of a propeller blade and collided with terrain (NTSB/AAR-93-08). All of the occupants were killed, and the airplane was destroyed. The Safety Board attributed the loss of the propeller to a reduction in the fatigue strength of the hub material, combined with exposure to higher-than-normal cyclic loads during ground operations when the propeller vibrated in the reactionless mode. The investigation revealed that during certification testing of the Hartzell HC-B4 propeller on the MU-2B airplane, a reactionless mode of vibration was identified with the peak stress occurring at a propeller speed of 1,079 rpm. As a result, the propeller was prohibited from continuous operation on the ground below 1,145 rpm. The Safety Board did not find evidence that the test was repeated using propeller blades altered to conform to the minimum dimensions specified in the repair limit criteria of Hartzell's HC-B4 propeller maintenance manual.

[50]Propeller rpm expressed as a percentage of the maximum operational limitation.

[51]The test airplane was subjected to the propeller wash of a second airplane to simulate normal ground operations in a quartering tailwind. This was accomplished to determine the high stress peaks of the propeller blade associated with the 2P excitation frequency within the normal propeller rpm range.

separately, the actual resonant frequency of the accident blade could have been slightly different than the frequencies measured in these tests.

Following the accident, Hamilton Standard conducted an independent blade stress survey in the latter part of 1995 and presented its report as part of a technical presentation to Safety Board investigators on February 2, 1996 (see Appendix D for Summary of Results, Conclusions and Recommendations). The 1995 stress survey also consisted of a flight and ground test, using four instrumented blades on both engines with two taper bore configurations. Of the four blades, one blade had zero service time, and the other three blades had approximately 12,000 service hours. The survey concluded that only small differences[52] from previous stress level surveys were observed, including those from the original certification and the postaccident test referenced above. The highest vibratory stress measured in flight was reported to be about 6,000 pounds per square inch (psi). The highest ground running peak stress was reported to be about 18,000 psi. This occurred with quartering tailwinds when the propeller passed through the range corresponding to vibration of the blade twice per revolution in the first flat-wise mode (2P/1f).

After the ground tests were completed, Hamilton Standard initiated actions to modify the EMB-120 Airplane Flight Manual and Maintenance Manual Limitations Sections with revised language to reduce the maximum propeller Np limit during ground operation from 65 to 60 percent. On December 20, 1995, airworthiness authorities in Brazil and the FAA approved temporary revisions to the language as follows:

> Airplane Flight Manual: Condition Levers must be in MIN RPM position during all ground operations, except when cleared for takeoff or during landing roll. Power Levers must remain at or below Flight Idle during all ground operations, except for brief (approximately 5 seconds) excursions as needed to maneuver the airplane.

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[52]The vibration and loads survey was conducted by Hamilton Standard on the 14RF propeller on an Embraer EMB-120 airplane. A possible small downward shift was discovered in the 2P resonant frequency relative to the 1985 certification test data. The downward shift was attributed by Hamilton Standard to normal wear and mass properties in the propeller blade from normal operation.

CAUTION: GROUND OPERATION ABOVE FLIGHT IDLE SIGNIFICANTLY INCREASES PROPELLER STRESS UNDER CERTAIN ADVERSE WIND CONDITIONS (E.G., TAILWINDS OR REAR CROSSWINDS). OPERATION IN THIS RPM RANGE MUST BE AVOIDED TO THE MAXIMUM EXTENT PRACTICABLE.

Maintenance Manual: Propeller System Operating Limitations, To prevent excessive propeller stress, do not operate above 60% Np unless the wind is less than 18.5 Km/h (10 Knots) or the airplane is headed into the wind + or - 45 degrees. Wind direction must be monitored locally at the run-up site.

1.17 Organizational and Management Information

1.17.1 Hamilton Standard Division, United Technologies Corporation

Hamilton Standard Division, Windsor Locks, Connecticut, has produced aluminum blade propellers with taper bores since 1958. More than 10,000 such blades are in use on C-130 and P-3 military airplanes. Composite blade propellers were introduced for military airplanes in 1974. Their use was expanded to regional (commuter) airplanes in 1978. Since that time, regional airplane propellers equipped with more than 15,000 blades that are fabricated with an aluminum spar and an aerodynamic shell of composite materials have accumulated in excess of 17 million flight hours.

A customer support facility for regional propeller inspection and repair was opened in East Windsor, Connecticut, in 1989. Hamilton Standard's engineering support continued to reside with the manufacturing facilities at Windsor Locks.

From 1989 through 1990, regional propeller inspection and repair expanded to facilities in Long Beach, California, and Maastricht, the Netherlands. In 1993, the regional propeller customer support center was moved from East Windsor, Connecticut, to a facility in Rock Hill, South Carolina.

1.17.2 Hamilton Standard Propeller Customer Service Center

Selected engineering and management personnel from the Hamilton Standard Division, Windsor Locks, were transferred in 1993 to the new regional propeller Customer Support Center in Rock Hill. Management at the Rock Hill facility hired technicians from a large pool of local area applicants and trained them to perform various propeller blade repairs. The facility was certificated by the FAA to begin repairing propeller blades in February 1994.

As a result of the two propeller blade failures in March 1994,[53] and the resulting ultrasonic inspections of the taper bore mandated by the FAA[54] in May 1994, there was a sudden increase in the number of propeller blades requiring inspection and repair in May and June 1994. The accident propeller blade was one of the blades returned to Hamilton Standard as a result of the inspection. The taper bore inspection and repair of the accident blade was performed at Hamilton Standard's Customer Support Center in Rock Hill between June 7, and June 9, 1994.

According to Hamilton Standard work records from May and June 1994, the technician who performed the taper bore inspection and repair of the accident blade worked between 8 and 26 hours of overtime each week, in addition to his normal work week.

1.17.2.1 Employee Training at Hamilton Standard Customer Service Center

According to the Engineering Manager in Rock Hill, new technicians at the facility received approximately 250 hours of training on a specific propeller blade repair before they are permitted to make repairs without direct supervision. However, the technician who made the taper bore repair to the accident blade was transferred from the nickel sheath and fiberglass repair area of the shop and had received 250 hours of training in connection with that position. In addition, he received approximately 90 hours of additional on-the-job training (OJT) on the taper bore repair. This technician had a background in automotive repair. His additional OJT training on the taper bore repair procedure was administered by the

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[53]Details of the two previous failures are contained in Section 1.16.2.

[54]AD 94-09-06 required an ultrasonic inspection of the taper bore. (See Section 1.16.3 for details on the AD.)

facility Engineering Manager, who had other responsibilities in addition to employee training.

The investigation revealed that during the time the accident blade was being repaired, the technicians at the service centers had not been provided a photograph or model illustrating the appearance of corrosion or cracking in a taper bore. Neither the Engineering Manager nor the technician who performed the inspection and repair of the accident blade had ever seen a crack in the taper bore of a blade. Several months after the accident blade was inspected and repaired, all the service center technicians were provided with an enlarged color photograph of taper bore corrosion, a model and an instructional video.

1.17.3 Designated Engineering Representative

The FAA annually appointed several Hamilton Standard engineering employees based in Windsor Locks to serve as Designated Engineering Representatives (DER) in propeller systems to approve certain engineering information.[55] Those DER duties normally represented about 20 to 30 percent of his or her workload. There were nine DERs certificated to support propeller systems at the time of the accident. Under an agreement with the FAA, Engine and Propeller Directorate, DERs have authority to approve certain engineering changes, repairs, service bulletins and maintenance manuals. However, the requirement for direct FAA approval was retained for changes affecting critical parts or single point failure components.

After the two blade failures in March 1994,[56] a Hamilton Standard DER[57] was in contact with the FAA, Engine and Propeller Directorate, several times a week during the development of the ultrasonic inspection requirements that were set forth in the ASB subsequently mandated by AD 94-09-06, and the taper bore repair procedures contained in PS960 and PS960A. The DER was

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[55]In accordance with 14 CFR 183.29(f), a propeller engineering representative may approve engineering information relating to propeller design, operation, and maintenance, within limits prescribed by the Administrator of the FAA, whenever the representative determines that information complies with applicable FARs.

[56]See Section 1.16.2 for details.

[57]The DER who was the central figure in the activity related to this accident was initially appointed in October 1992. He had 16 years of experience at the Windsor Locks propeller facility. He holds a Bachelor of Science degree in astronomy and a Master's Degree in business administration. He also attended a university-level course in aircraft accident investigation.

involved in developing the ASB and PS960/960A. The DER was familiar with the issue of taper bore corrosion, the formation and functions of the Rock Hill Customer Service Center, and the white light borescope inspection technique used to search for evidence of cracks and corrosion, and to reject blades for engineering evaluation. After the accident, he told investigators that based on his knowledge of the March 1994 accidents, he believed the white light borescope inspection would be adequate to enable technicians to detect corrosion pits in the taper bore of the size that led to the cracks that caused the two previous failures.

The DER stated that he was not aware of the discussions between engineering managers at Windsor Locks and the Customer Service Centers in which it was decided to extend the taper bore repair procedures outlined in PS960A beyond their intended use (to blend visible mechanical damage in taper bores) to blend ultrasonic indications that were not related to visible mechanical damage. He said that this lack of coordination from the engineering department was atypical.

1.17.4 FAA Certification Engineer

The FAA certification engineer[58] responsible for Hamilton Standard regional propellers reviewed the fracture analysis of the two blade fractures in March 1994. He determined that the FAA should retain direct approval authority for the data and the inspection and repair techniques used for PS960/PS960A because, based on the two blade failures that resulted from taper bore corrosion, he considered the taper bore to be a critical part.[59] The Certification Engineer also required that the repair for mechanical damage in the taper bore be accomplished only at Hamilton Standard repair facilities.

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[58]The FAA certification engineer had been with the FAA Engine and Propeller Directorate for 9 years at the time of the accident. He holds a Bachelor of Science degree in mechanical engineering. He has 30 years of government experience, primarily with U.S. Navy programs. His experience includes propellers for surface ships and submarines.

[59]FAA Order 8110.37A (DER Guidance Handbook), Paragraph 14.h.(1)states that "The DER must obtain specific authorization from the appointing ACO [Aircraft Certification Office] prior to initiating approvals for repairs or alterations. An authorized DER may approve technical data for major repairs and alterations without first notifying the project ACO, except when the part is critical or life limited. For critical or life limited parts, the DER must contact the project ACO for guidance."

The Certification Engineer (like the DER) stated that he was not aware that blending procedures outlined in PS960A (originally approved as a repair for areas with visible mechanical damage) had been extended by Hamilton Standard engineers as an authorized repair to areas in which ultrasonic indications were present without visual evidence of mechanical damage.

1.18 Additional Information

1.18.1 Safety Board Recommendations

The Safety Board issued the following three Safety Recommendations to the FAA on August 25, 1995, which was 4 days after the accident:

> <u>A-95-81 (Class I, Urgent Action)</u>
> Immediately implement the ultrasonic inspection program on Hamilton Standard propeller blades cited in paragraph (a)(2) of airworthiness directive (AD) 95-05-03, irrespective of prior compliance with paragraph (d) of the AD. Require the initial inspection before further flight on any propeller blades that have accumulated 1,250 cycles since the last ultrasonic inspection or since the visual and borescope inspection required by paragraph (d) of the AD.
>
> <u>A-95-82 (Class II, Priority Action)</u>
> Conduct a vibration and loads survey and analysis of the propeller installation on the Embraer EMB-120 airplanes with applicable Hamilton Standard propellers throughout the ground and flight operating range of the engine with specific consideration for the effects [that] propeller in-service wear, maintenance, or other changes may have on the resonant frequencies. Based on the findings, broaden the survey and analysis to other installations as appropriate.
>
> <u>A-95-83 (Class II, Priority Action)</u>
> Review the current overhaul and inspection requirements for all Hamilton Standard 14 series propeller blades for which the taper bore hole has been shotpeened to determine whether additional inspections or maintenance should be required.

Regarding Safety Recommendation A-95-81, on August 25, 1995, the FAA issued a telegraphic AD (T95-18-51) requiring that certain blades installed on EMB-120 aircraft that had ultrasonic crack indications discovered as a result of inspections required by AD 94-09-06 or AD 95-05-03, been reworked, and had been returned to service, be removed from service within the next 10 flight cycles and be replaced with serviceable parts. The telegraphic AD also required that propeller blades installed on aircraft other than the EMB-120 meeting the same criteria (ultrasonic crack indications reworked and blade returned to service) be inspected ultrasonically for cracks within the next 10 flight hours and every 1,250 cycles thereafter. Any blades removed from service as a result of the AD could not be returned to service. On January 16, 1996, the Safety Board classified Safety Recommendation A-95-81 "Closed--Acceptable Alternate Action."

Regarding A-95-82, on July 24, 1996, the FAA informed the Safety Board that it conducted the requested vibration and loads survey. The FAA reported that the survey substantiated the results of past stress surveys indicating that no new high stress conditions were uncovered, and that it did not show that further evaluations were needed on other installations. However, to limit propeller exposure to known high vibratory stresses during ground operation, on December 27, 1995, the FAA issued AD 95-25-11, which requires installation of a placard reading "Avoid Np Above 60% During Ground Operations," and also requires revising the EMB-120 Airplane Flight Manual and maintenance program to limit the rotational speed of the propeller during ground operation. In its Final Rule, published in the *Federal Register*, the FAA stated that the AD is considered "an interim action until final action is identified, at which time the FAA may consider further rulemaking." Based on the FAA's interim actions and the statement contained in its announcement of the Final Rule, on November 15, 1996, the Safety Board classified Safety Recommendation A-95-82 "Open--Acceptable Response."

Regarding A-95-83, on July 24, 1996, the FAA informed the Safety Board that its review of the overhaul and inspection requirements for all Hamilton Standard 14RF, 14SF and 6/5500/F blade designs for which the taper bore hole has been shotpeened showed that additional action should be taken. On April 24, 1996, it issued AD 96-08-02, requiring repetitive ultrasonic inspection of the blades until they are repaired and restored to their certificated strength. The repair of EMB-120 blades was required to be accomplished by August 1996, and all other blades will be repaired by February 1997. Since the actions of the FAA are responsive to the intent of the recommendation, on November 15, 1996, the Safety Board classified Safety Recommendation A-95-83 "Closed--Acceptable Action."

On June 27, 1996, the Safety Board issued the following additional safety recommendations to the FAA:

> A-96-33
> Conduct a design review of the Embraer EMB-120 flight data recorder system, with emphasis on potentiometer failures, and mandate design, installation, and/or maintenance changes, as necessary, to ensure that reliable flight control data are available for accident/incident investigation.
>
> A-96-34
> Require Embraer EMB-120 operators to perform a flight data recorder (FDR) readout or a potentiometer calibration test per section 31-31-00 of the EMB-120 Maintenance Manual every 6 months until FDR sensor design, installation, and/or maintenance improvements are incorporated.

On September 5, 1996, the FAA responded that it had initiated a design review focusing on the potentiometers and associated attaching hardware, and would determine a course of action when the review is complete. The FAA also stated that it would contact the manufacturer and coordinate the necessary maintenance instructions with an appropriate inspection interval. Therefore, on October 15, 1996, the Safety Board classified both A-96-33 and A-96-34 "Open--Acceptable Response," pending final action.

1.18.2 Postaccident Hamilton Standard and FAA Actions

As a result of the accident and Safety Board recommendations, on August 25 and 28, 1995, the FAA issued AD T95-18-51 and AD 95-18-06, respectively, which required that all blades installed on EMB-120 aircraft that, like the accident blade, had been removed from service in accordance with AD 94-09-06 (or 95-05-03) and been reworked and returned to service be immediately removed from service, and it required an ultrasonic reinspection of all other 14RF, 14SF, and 6/5500/F blades (a total of approximately 15,000 blades) on a 1,250 cycle interval.

As a result of the Luxair accident, Hamilton Standard developed an additional series of service bulletins that were mandated by the FAA in Airworthiness Directive (AD) 95-24-09, issued on November 16, 1995. This AD required an ultrasonic shear wave inspection on the propeller shank for cracks or indentations. Four blades were removed from service as a result of this AD.

As the inspections mandated by AD 95-18-06 began to take place, Hamilton Standard recognized a need for a detailed reevaluation of the adequacy/appropriateness of this inspection procedure because the ultrasonic inspections continued to reject blades with no apparent discrepancies on the taper bore. This reevaluation showed that the minimum detectable size of a taper bore crack varied widely. That is, it could be much greater (and, in some cases, smaller) than previously believed. Hamilton Standard found that there were differences in the calibration blocks[60] distributed for the inspection, and that differences in the thickness of the surface composite layers and in the transmitability of the ultrasonic beam through the aluminum spar could substantially affect the inspection results.

Coincidentally, Hamilton Standard performed a risk analysis of the failed blades to resolve inconsistencies in the crack growth data from the Inter-Canadien, Nordeste, and ASA blade separations. Results from a NASA-developed fracture mechanics FASTRAN program were integrated into the risk analysis. Hamilton Standard concluded that for some blades of each model, the 1,250 cycle inspection interval using the original ultrasonic technique provided insufficient safety margins for the detection of taper bore cracks. Thereafter, Hamilton Standard issued another series of ASBs for the 14RF, 14SF, and 6/5500/F blades, containing a newly-developed ultrasonic inspection technique with a customized calibration procedure for each blade and a reduced inspection interval. For the 14RF blades used on the EMB-120 airplanes, the inspection interval was reduced to 500 cycles. The FAA issued AD 96-01-01, effective on January 19, 1996, requiring the improved ultrasonic inspection technique and mandating the reduced cyclic inspection interval.

In March 1996, Hamilton Standard issued ASB 14RF-9-61-A94 to repair and restore the taper bore surface to its original surface finish (with shotpeening) on all model 14RF-9 propeller blades installed on EMB 120

[60]Test specimens manufactured with defects of known sizes used to adjust the threshold of pass/fail for ultrasonic inspection equipment.

airplanes and on similar model blades installed on other commuter-type airplanes. On April 24, 1996, the FAA issued AD 96-08-02, which required that all blades of the affected propellers be repaired by specific end dates. The end date for the 14RF-9 model blade was August 31, 1996, and for other affected models is February 28, 1997. The repair procedure included removal of a layer of spar material from the taper bore, followed by an eddy current inspection, fluorescent penetrant inspection (FPI), removal of an additional layer of material, a wall thickness check, shotpeening, and the application of a corrosion-protective coating. Hamilton Standard also conducted fatigue tests on a set of blades with the minimum allowable remaining wall thickness between the taper bore and the outside of the spar, thereby verifying the fatigue characteristics of blades repaired in this manner. Once a blade is repaired, the requirements for ultrasonic inspection are eliminated, and further visual inspections of the taper bore will take place only as part of the major inspection that is required every 9,500 flight hours. There are no calendar-based inspection requirements.

Hamilton Standard informed the Safety Board that all 14RF-9 blade repairs were accomplished within the time limit established in the AD. The Safety Board also notes that the Component Maintenance Manual (CMM) for all Hamilton Standard model 14FR, 14SF, and 6/5500F airplane propellers (which includes all propellers used in commuter operations), has been amended to include a recurring inspection of the taper bore.

2. ANALYSIS

2.1 General

The flightcrew was trained, certificated and qualified to conduct the flight, and the flight was conducted in accordance with applicable FARs and company requirements. The flight attendant also was appropriately trained and qualified. The flightcrew was in good health and held the proper FAA medical certificates. There was no evidence that the performance of any crew member was impaired by alcohol, drugs, or fatigue.

The airplane was maintained in accordance with applicable FARs and company Operations Specifications. A review of the airplane's maintenance records and operating history did not reveal any maintenance discrepancies or mechanical anomaly that would have either caused or contributed to the accident.

Evidence from the CVR, FDR, and examination of the powerplants, reduction gear boxes, and propellers indicated that the engines were operating normally during the flight until the loss of a major portion of one propeller blade on the left engine. After the propeller blade separation, the combination of the resulting loss of left engine thrust, increased drag from a deformed engine nacelle and the three blades retained in the propeller hub, and added frontal drag from external sheet metal damage, degraded airplane performance, preventing the flightcrew from arresting the airplane's descent or making rapid changes in its direction of flight making a forced landing necessary. The Safety Board concludes that because of the severely degraded aircraft performance, the flightcrew's actions were reasonable and appropriate during their attempts to control and maneuver the airplane throughout the accident sequence and were not a factor in this accident.

2.2 Analysis of the Propeller Blade Failure

The Safety Board concludes that one of the four blades from the left engine propeller separated in flight because a fatigue crack that originated from multiple corrosion pits in the taper bore surface of the blade spar propagated toward the outside of the blade, around both sides of the taper bore, then reached critical size. (See Section 1.16.1.)

Results of investigations conducted in two previous propeller blade failures in 1994, one in Brazil with this model blade and the other in Canada with a similar model blade, indicated that corrosion was produced when entrapped moisture reacted with residual chlorine in a bleached cork used to retain the lead wool in the taper bore hole of the propeller. The accident blade exhibited a nearly continuous layer of oxide deposits on the initial 0.049 inch of the crack depth. These deposits contained a substantial amount of chlorine. The Safety Board found that the ASA propeller blade contained corrosion damage (pitting) in the taper bore and the oxide layer in the origin area of the fatigue crack in the separated ASA propeller blade, as did the two previous failed propellers. Because the oxidizing condition and the cork containing chlorine were eliminated from the accident blade per PS960A during the June 1994 repair at the Hamilton Standard Customer Support Center in Rock Hill, oxide deposits would not be expected to have formed during further crack propagation after the PS960A repairs. Therefore, the extent of the oxide layer on the fracture (to a depth of 0.049 inch below the surface) was indicative of the size of the crack at the time of the Rock Hill repair activities.

2.2.1 The Accident Blade's June 1994 Inspection, Repair, and Return to Service

2.2.1.1 Inappropriate Use of PS960A Blending Repair

As discussed in Section 1.16.4, the technician who inspected and repaired the accident blade first confirmed the rejectable ultrasonic indication, and then visually examined the taper bore for evidence of corrosion, pits or cracks using a white light borescope. He wrote on the shop traveler, "No visible fa[u]lts found, blend rejected area," and used the blending repair procedure set forth in PS960A to remove the ultrasonic indication. The blended area was later found to be the site of a crack originating in corrosion pits.

Apparently, Hamilton Standard engineering originally intended PS960A only to remove possible sources of stress concentration by blend-repairing mechanical damage (visible tool marks) within the taper bore of any blade, without regard for whether the surface was shotpeened or not shotpeened. The instructions in PS960A with regard to the surface finish of the taper bore specifically stated, "No unblended mechanical damage is allowed." The FAA reviewed and approved the repair for this purpose. However, the use of PS960A blending repair was expanded by Hamilton Standard engineering to blend the area of ultrasonic indications even when there was no apparent mechanical reason (visible tool mark) associated with the ultrasonic indication.

The Safety Board considered whether it was appropriate, from an engineering perspective, for Hamilton Standard to extend the applicability of PS960A beyond its original purpose (blending of mechanical damage), and to authorize its use for removing ultrasonic indications caused by shotpeen impressions. Surface irregularities created by shotpeening are, in effect, a form of mechanical surface alteration, and the concept of blending mechanical damage is not per se objectionable, so long as there are no cracks or other defects in the area being blended.[61] Based on the prior blade separations (both of which involved cracks originating from corrosion), Hamilton Standard had no reason to believe that mechanical damage in taper bores was causing cracks. Therefore, the Safety Board concludes that Hamilton Standard's engineering decision to use the PS960A blending repair to remove ultrasonic indications caused by a shotpeened taper bore surface was technically reasonable.

Although the decision by Hamilton Standard engineers to extend the applicability of PS960A to impressions in shotpeened taper bores was technically reasonable, the procedure by which that decision was communicated to others within Hamilton Standard was deficient. The decision was communicated during a conference call involving top engineering managers, but it was not discussed with the DER or the FAA. It was then documented in a memorandum that contained no indication that it represented an extension of PS960A, and made no reference to shotpeened taper bores. The memorandum stated only that blades returned as a result of an ultrasonic inspection should be reworked "per PS960A."[62] The substance of the decision was then verbally transmitted by the engineering manager of the Rock Hill facility to his staff but, as evidenced by the technician's belief that he was authorized to use the PS960A blend repair to remove ultrasonic indications on both shotpeened and unshotpeened blades, it was either misstated or misunderstood.

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[61]The blending process could mask the existence of a crack if done improperly (see Section 2.2.1.2, discussing effects of failing to restore the original surface finish) or if enough of the crack is removed by the blending so that the ultrasonic indication is reduced to a nonrejectable height.

[62]See Section 1.16.3 for more information about the circumstances surrounding the decision to extend PS960A.

Although Hamilton Standard management asserted that this expansion of the use of the PS960A blending repair procedure applied only to ultrasonic indications in shotpeened taper bores, it was understood, at least by the technician who worked on the accident blade, as being applicable to unexplained ultrasonic indications in unshotpeened taper bores as well. Given that unexplained ultrasonic indications in the taper bore area represent an unknown condition suggestive of cracking and, further, that (according to statistical data provided by Hamilton Standard) blades without shotpeened taper bores are susceptible to earlier corrosion and to cracking once corrosion begins, Hamilton Standard management (both in Windsor Locks and in Rock Hill) should have made certain that the technicians performing the repair clearly understood that the extension of PS960A was intended for shotpeened taper bores only.

If the technician had clearly understood that he was not authorized to blend unexplained ultrasonic indications in unshotpeened taper bores, he would have rejected the accident blade, or at least sought additional guidance from his engineering manager as to how to handle the unexplained ultrasonic indication. In either case, the accident blade would not have been subjected to the PS960A blend repair, which masked the existence of the crack (see Section 2.2.1.2), and would not likely have been returned to service. The Safety Board concludes that the manner in which the unapproved extension of PS960A was documented and communicated within Hamilton Standard, and the lack of training on the extension, created confusion and led to misapplication of the blending repair to unshotpeened blades with unexplained ultrasonic indications, allowing the accident blade to be placed back into service with an existing crack, thus contributing to this accident. The Safety Board is concerned about the adequacy of Hamilton Standard's internal communication and documentation. This issue is further addressed in Section 2.6.1.

2.2.1.2 Sanding (Blending) of the Accident Blade

As noted in Section 1.16.1, although PS960A required that the blended area be restored to its original surface finish, the sanding marks in the blended area of the accident blade were much rougher than the original surface finish. The sanding marks left by the blending appeared to have smeared some of the corroded surface, suggesting that the sanding took place after the corrosion had formed. Although some of the fatigue initiation area was along the sanding marks, the fatigue cracking initiated from corrosion pitting damage that extended below the taper bore surface to a depth much greater than the sanding marks.

Therefore, the Safety Board concludes that the sanding marks left by the PS960A blending repair did not contribute to the initiation of the fatigue crack in the accident blade. However, as discussed below, the sanding marks may well have allowed the cracked blade to pass the ultrasonic inspection following the PS960A blending repair.

Following the PS960A blending repair, the accident blade was again ultrasonically inspected, and this time, neither a rejectable[63] nor a reportable[64] indication was generated. This allowed the blade to be returned to service, and it was installed on the accident airplane. Safety Board laboratory measurements indicated that only a minimal amount of material (less than about 0.002 inch) was removed from the taper bore surface during the PS960A blending repair process. Although removal of this amount of material would have slightly decreased the size of the crack, it is unlikely that such a small decrease, by itself, would have reduced the ultrasonic indication from 60 or 52 percent (the magnitude of the indications recorded in the previous on-wing inspection and upon receipt at Rock Hill, respectively) to below 40 percent (the minimum level that must be recorded on the inspection form).

The ultrasonic inspection beam must reflect off both the defect and the taper bore surface to bounce back to the transducer and be detected. However, the surface finish in the taper bore was much rougher than the original finish, and the sanding scratches that remained in the taper bore surface would have caused the ultrasonic beam to scatter or become diffused as the beam reflected from the taper bore surface. It is likely that this was the major reason for the decrease in the size of the ultrasonic indication. Therefore, the Safety Board concludes that the failure to restore the taper bore surface to the original surface finish during the blend repair, as required by PS960A, was a factor that caused the reduction of the ultrasonic indication that allowed the blade to pass the final ultrasonic inspection and to be returned to service, and thus contributed to the accident.

In trying to determine why the technician did not properly perform the blend repair, the Safety Board noted that PS960A did not describe or refer to procedures that would ensure that the blended area was restored to its original surface finish but simply stated this as a requirement. The technicians were provided with examples of the required surface finish, which were designed to

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[63]50 percent or over of full-scale height.

[64]40 percent or over of full-scale height.

assist them in determining whether the blended surface finish was appropriate. However, Safety Board investigators found that it was difficult to distinguish whether a particular surface finish varied from the examples. Investigators also considered the possibility that the technician's improper performance of the blend repair was related to inadequate training in the repair,[65] his automotive background, or the long hours he was working at the time.[66] However, after extensive records examination and questioning of the technician, his supervisor and others at Hamilton Standard, it was not possible to determine whether, or to what extent, these factors contributed to the technician's failure to properly restore the blended area to its original surface finish.

Although the PS960A blend repair is no longer being used, Hamilton Standard uses blending (sanding) in a variety of other propeller repair procedures. In view of the potential for improperly performed blend repairs to mask existing corrosion and cracks, the Safety Board believes that the FAA should require Hamilton Standard to review and evaluate the adequacy of its tools, training and procedures for performing propeller blend repairs, and ensure that those blend repairs are being performed properly.

The technician who performed the blend repair on the accident blade was neither an FAA-certificated mechanic nor, as an employee of a 14 CFR Part 145 repair station, was he required to be certificated. The technician stated that he was permitted to sign off the work that he was qualified to perform. The shop traveler form, which listed the requirement for the 63 RMS surface finish, showed that the technician had signed off that he had accomplished the taper bore blend repair. However, except for the subsequent ultrasonic inspection that was to determine if the rejectable indication had been eliminated, there were no other inspections of the accident blade. 14 CFR Part 65.87 states, in part, that a certificated mechanic may return a propeller blade to service after he has repaired and inspected, or supervised the repair and inspection of, that part. 14 CFR Part 145.45 specifies that a repair station must have an inspection system with qualified personnel to determine the airworthiness of the parts being altered or maintained. Therefore, the Safety Board believes that the FAA should review the need to require inspection ("buy back") after the completion of work that is performed by

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[65]He received 90 hours of on-the-job training from the engineering manager, whose primary duties did not relate to training.

[66]His work records indicate that during May and June of 1994, he worked between 8 and 26 hours of overtime each week.

uncertificated mechanics at Part 145 repair stations to ensure the satisfactory completion of the assigned tasks.

2.2.2 Adequacy of Hamilton Standard Procedures for Detecting Corrosion

2.2.2.1 Borescope Inspection

From an engineering and airworthiness perspective, the appropriateness of the PS960A blending repair procedure rests on the premise that there are no cracks or corrosion in the area being blended. However the investigation revealed that during the initial stages of inspecting and repairing the 490 returned blades, although great emphasis was given to the development and implementation of the PS960A repair procedure, little consideration was given to the adequacy of the procedures being used to detect cracks and corrosion.

The inside of the taper bore is less than 1 inch in diameter. Visual inspection of the interior of the taper bores was accomplished using a borescope that did not provide low angle (indirect) illumination, which would have highlighted changes in the surface depth, such as those related to subtle corrosion. Instead, the borescope inspection used direct illumination, which produced a glare and made visual detection of corrosion difficult. Using this direct-light borescope resulted in a view of the taper bore interior that would reveal gross discoloration or widespread corrosion but that would not readily reveal minor corrosion or small cracks. In addition, the glare could have caused eye strain over time. For these reasons, the probability of detection of cracks or corrosion decreased over the course of a work period.

Corrosion in earlier blade failures, such as the Inter-Canadien accident, was widespread and deep, and most likely would have been readily detected by a visual inspection, even with a direct light source. However, the corrosion involved in the accident blade was shallow, diffused and more difficult to recognize as corrosion. In fact, the ultrasonic inspection performed prior to the PS960A repair directed the technician to the location of the corrosion pits, but upon visual examination of that area, the technician reported that he did not see "visible faults." Safety Board investigators, and other experts who have examined the accident blade, agreed that inspection with a direct light source might not have adequately highlighted the corrosion and cracking that had already developed.

(An FPI inspection technique was later introduced, using a black light borescope, which would more readily reveal cracks and corrosion.)

In addition, at the time the accident blade was inspected, the movement of the borescope into the taper bore hole and circumferentially around the hole was controlled by hand, and there was no procedure to ensure that the entire inner surface was inspected. Therefore, it is possible that the visual inspection of some blades, possibly even the accident blade, might have been incomplete. (Mechanical assistance to control the location of the borescope was introduced later.)

Therefore, the Safety Board concludes that the borescope inspection procedure developed and used by Hamilton Standard in June 1994 to inspect returned blades that had rejectable ultrasonic indications for evidence of cracks, pits, and corrosion was inadequate and ineffective.

2.2.2.2 Technician Training and Supervision

Investigators were informed that technicians at Hamilton Standard, Rock Hill, normally received approximately 250 hours of general training before they began working on propellers being returned to airworthy condition. Because the technician who accomplished the taper bore repair to the accident blade transferred from another shop area (fiberglass and nickel sheath replacement and repair), he received his 250 hours of training in that area. After transferring to the taper bore area, he received about 90 hours of on-the-job training (OJT) for taper bore repair. However, that training was deficient because he was not provided a photograph or model of what corrosion or cracking looked like inside a taper bore. It was not until the fall of 1994 that such material was provided (in the form of a photographic example of corrosion and an instructional video), as part of a group of inspection improvements covered in a Component Maintenance Manual revision and Service Bulletin 14RF-9-61-70A. Compliance with that Service Bulletin was not required until March 23, 1995, with AD-95-05-03.

In the absence of a photograph or model of different types of potential corrosion, the technician might have expected the type of gross corrosion or cracking more familiar to his automotive background and, thus, failed to realize the significance of corrosion with a more subtle appearance, such as that present in the accident blade. This problem was most likely compounded by the poor borescope inspection techniques discussed above. Further, technician training in how to perform the taper bore repair procedure was provided by the Rock Hill facility engineering manager, who had numerous additional responsibilities at the time. Moreover, because the other inspectors were also recently hired and trained and were relatively inexperienced in finding corrosion in the taper bore of aluminum aircraft propellers, they were unable to provide guidance or help to each other.

The Safety Board concludes that although the introductory technical training to prepare the new, inexperienced workforce at Hamilton Standard's Rock Hill Customer Service Center may have been adequate, the specific training initially given to technicians who inspected blades returned to Rock Hill as a result of the on-wing ultrasonic inspections, including the accident blade, was not adequate to ensure that they were proficient in the detection of taper bore corrosion or associated cracks. (Hamilton Standard eventually improved its training by providing photographs and an instructional video.)

2.2.2.3 Adequacy of Improvements to Inspection Procedures

The Safety Board is concerned that Hamilton Standard and the FAA determined that repetitive ultrasonic inspections (per AD 95-05-03) could be terminated by a one-time visual borescope inspection to detect corrosion or by a previous PS960A repair, even though the probability of detection (POD[67]) for the visual borescope method would be less than 100 percent. As a result of this determination, when the ASA accident blade was visually inspected, repaired, and marked with "PS960A" (which incorporated a borescope inspection of the taper bore), the blade was exempt from further ultrasonic or visual inspections. Hamilton Standard's and FAA's expectations for a visual inspection were unrealistic, particularly when using hand-held borescopes with a direct light source, and when the technician did not have explicit examples of what was a rejectable visual condition.

In the months following the first two failures in March 1994, Hamilton Standard identified inadequacies in the inspection process and generated improvements to address these inadequacies. Specifically, Hamilton Standard provided a photographic example of corrosion, a training video, a borescope feed adapter, and a process upgrade to FPI. However, when these improvements in the

[67]The probability of detection (POD) for a visual inspection is dependent upon many variables including the flaw size, environment, ocular assistance devices, training and operator experience and fatigue.

inspection methods were made, Hamilton Standard either did not recognize or was not concerned that taper bore flaws, such as the crack in the ASA blade, might have gone undetected during the previous inspection and repair process before the improvements were made because Hamilton Standard did not implement retroactive inspection of those blades that had been inspected previously and returned to service under inspection standards and processes that were no longer considered adequate.

Because the accident blade had been rejected once for an ultrasonic indication caused by the crack that ultimately propagated to cause separation, it is very likely that the existing crack would have been redetected if the accident blade had been subjected to additional ultrasonic inspections (at the required 1,250 cycle intervals, per AD 95-05-03) after it was returned to service following the Rock Hill maintenance activities. If the accident blade had been subjected to the recurrent on-wing ultrasonic inspections required by AD-95-05-03, it would have received one inspection, and possibly a second, before the crack reached critical size and the blade separated. Therefore, the Safety Board concludes that Hamilton Standard's failure to recommend, and the FAA's failure to require, repetitive ultrasonic inspections for all propellers (particularly those already inspected when there were recognized shortcomings in the inspection process) contributed to the accident because the crack in the accident blade would likely have been detected in a recurrent ultrasonic inspection.

2.3 Effect of Blade Resonance

When Hamilton Standard attempted to model the growth of a taper bore fatigue crack in the fall of 1995, the results of the initial fracture mechanics analysis of the fracture of the Inter-Canadien (ATR-42) blade were consistent with the initiation and propagation of the crack from the corrosion pits in that blade. However, the analysis indicated that cracking should not have developed from the smaller corrosion pits that were found at the origin area of the ASA blade and the Nordeste blade (both from EMB 120 airplanes).

To more fully understand the ASA taper bore fracture mechanics, Hamilton Standard then used a NASA-developed program called FASTRAN, which addressed the magnitudes and numbers of stress cycles required for corrosion pits to form cracks and for the cracks to propagate to critical size. Using the measured flaw sizes from the accident blade and the two previous fractures, the FASTRAN program was able to predict the stress cycles needed for the crack in each of the blades, including the ASA blade, to propagate from the initial flaw size to fracture. Hamilton Standard indicated to the Safety Board that for a corrosion pit to initiate a crack, especially for small pit sizes, such as in the ASA blade, a blade would have to have been subjected to a very high number of stress cycles of the most severe type that the blade would normally encounter in routine operations. Since a ground-air-ground (GAG) cycle[68] imparts severe stress to the blade only once per flight, Hamilton Standard engineers believed that 2P resonance (which occurs twice per revolution of the propeller) in adverse winds, perhaps during a maintenance ground run, contributed to the initiation of the crack from corrosion pitting and propagation of the crack while it was small. The FASTRAN program calculated that for a crack the size of the ASA crack at the time the blade was at Rock Hill (0.050 by 0.060 inch) to propagate to failure, an average of 50 maximum level 2P stress cycles would have to be accumulated each flight. This number of cycles could be accumulated in about 1.6 seconds of operation at the rpm range associated with 2P resonance during ground operation in adverse winds (quartering tailwinds).[69]

Through independent testing using a corporate-owned EMB-120 airplane, Hamilton Standard confirmed previous test results that the most severe stress cycles were the GAG cycles, and the vibratory stresses encountered during 2P resonance (which are about the same magnitude as the GAG stresses) in adverse winds during ground operations.

It should be noted that during the propeller ground tests conducted by Hamilton Standard (where stress levels up to 18,000 psi were measured), the test lasted for only 30 seconds. The 30-second interval might not have been of sufficient duration, with the given test conditions, to produce maximum possible stress. Additionally, the quartering tailwinds were generated by the propeller wash of a small executive turbopropeller aircraft. It is possible that stress levels in excess of 18,000 psi could be attained if the propeller were allowed to remain in the resonant condition in excess of 30 seconds or if the propeller was subjected to natural quartering tailwind conditions of higher velocity.

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[68]A GAG cycle included engine power application for takeoff, climb, cruise, descent and reverse thrust after landing.

[69]Ground operation in a tailwind or quartering tailwind causes the airplane to shake and buffet, which hampers the mechanic's ability to read instruments and perform any meaningful tests.

The Safety Board noted that ASA's operational procedures prohibited single-engine taxi. Because single-engine taxi increases the potential for ground operation in the resonant range, by requiring higher engine rpm to initiate and continue movements, it might be expected that other operators of EMB-120 airplanes that allow single-engine ground operation would have a higher incidence of cracks. That is, if a 2P resonant condition could be generated during normal ground operations and could initiate and propagate a fatigue crack, it would be more likely that cracking would occur on blades used by operators that allow single engine operation on the ground. However, this did not occur.

It is also possible that a 2P resonant condition was generated during some type of ground maintenance activity and that these stresses contributed to the initiation and propagation of the crack. However, ground operation in a tailwind or quartering tailwind is contrary to all standard maintenance practice and is prohibited in the EMB-120 maintenance manual. The Safety Board could find no documented evidence, and was not provided any information by Hamilton Standard, Embraer, Pratt and Whitney of Canada, or the operator, that the propeller was operated in a 2P resonant condition. Additionally, the EMB-120 cockpit was placarded, and there were cautions set forth in the airplane flight manual and engine maintenance manual to avoid engine operation above 65 percent Np range in adverse wind conditions. Safety Board investigators had a number of opportunities to observe whether there was compliance with these limitations, and they did not observe noncompliance.

Although ground operation in a tailwind causes the airplane to shake, the shaking is a result of disturbed airflow across the wings and fuselage and is not damaging. However, under such conditions, an increase of the propeller rpm into the resonant range would generate a reactionless vibratory mode in the propellers. This would be undetectable, especially during crosswind-induced airframe buffet. Such circumstances could arise at any time during ground operation in a strong quartering tailwind, such as while operating in the vicinity of jet wash from a large transport aircraft. With a population of more than 2,450 14RF-9 model blades in service on EMB-120 airplanes throughout the world, there have probably been many occasions when blades were operated in quartering tailwinds in excess of the 10 knots cautioned about in the flight manual and placards.

The Safety Board concludes that a combination of 2P resonance and GAG cycle stresses initiated the crack from the corrosion pits in the ASA blade and caused the crack to propagate to failure under normal operating conditions.

2.4 Adequacy of Vibration Testing

Hamilton Standard's 1983 and 1985 certification stress surveys were conducted using one instrumented blade with a second instrumented blade as a backup. None of the tests were conducted using blades that had previously been used in service. The 1995 stress survey conducted as a consequence of this accident included three instrumented blades that had approximately 12,000 service hours. The 1995 stress survey revealed a small but important difference from the 1983 and 1985 certification tests. Although no new high stress conditions were discovered, a small downward shift in the first flat-wise natural frequency was detected. This downward shift was attributed to normal wear and mass properties in the propeller blade from normal operation.

On April 19, 1993, the Safety Board investigated a propeller in-flight separation on an MU-2B-60 in Zwingle, Iowa. As indicated in the accident report, the Safety Board discovered that during certification testing of the Hartzell HC-B4 propeller on the MU-2B airplane, a reactionless mode of vibration was identified with the peak stress occurring at a propeller speed of 1,079 rpm. As a result, the propeller was prohibited from continuous operation on the ground below 1,145 rpm. The Safety Board did not find evidence that the test was repeated using propeller blades altered to conform to the minimum dimensions specified in the repair limit criteria contained in the Hartzell HC-B4 propeller maintenance manual.

The FAA recommends in Advisory Circular (AC) 20-66, Vibration Evaluation of Aircraft Propellers, in the chapter on vibration measurement programs, that propeller diameters should be tested at various lengths throughout the diameter range, to include the maximum and minimum diameters, and the cutoff repair limit. Although it is not explained in AC 20-66, testing a propeller blade at its cutoff repair limit is conducted presumably to ensure that the decrease in blade length does not alter the natural frequency to the extent that a resonant vibration condition could be entered while operating within the normal rpm range. AC 20-66 considers the expected loss of mass of a metal propeller blade following blend repair; however, the AC does not consider the expected mass gain with age of a composite propeller blade. Composite blades may gain mass with age with the addition of layers of paint, introduction of moisture, and patch repairs.

A review of AC 20-66, which includes a detailed discussion of the propeller vibratory phenomenon, does not explain that a propeller blade's natural vibratory response varies with varying conditions (i.e. mass gain, mass loss, variations in airfoil shape, etc.) and that adequate margin from a potentially coincident excitation frequency should be maintained. Consequently, the Safety Board concludes that the AC does not provide guidelines for adequate margin between a propeller blade's natural frequencies and its potentially coincident excitation frequencies over the life of the blade.

Therefore, the Safety Board believes that the FAA should revise AC 20-66 to include the vibratory testing of composite propeller blades that have been previously operated for a substantial number of service hours, and composite blades that have been altered to the limits set forth in FAA-approved repair manuals to determine the expected effects of age on propeller vibration and provide guidelines for rpm margin between a propeller blade's natural frequencies and the excitation frequencies associated with propeller operation.

2.5 Effect of Blade Failure and Analysis of Terminating Action

The forward half of the fractured front inlet case, found along the wreckage path, was attached to the reduction gear box (RGB) of the left engine. The RGB case was also fractured, empty of oil, and some internal gearbox components were missing. The in-flight fracture of the RGB case most likely resulted in the loss of the gearbox components and the venting liquid reportedly seen by the passengers.

Damage to the forward engine mounts and the front frame of the left engine nacelle indicated that the propeller RGB first separated upward at the inboard mount location, followed by the aft and outboard failure at the outboard mount location. Failure of the engine mounts were the result of overload stresses.

The imbalance loads associated with the separated blade on the accident airplane apparently exceeded the design strength of the RGB attachment points. In this instance, it appears that the RGB was retained on the airplane in an outboard displaced position, as observed by the passengers, from the time of propeller blade separation until the beginning of the initial ground impact.

Embraer's postcertification (September 1984) testing determined that the nacelle would not withstand a mid-blade or full-blade segment loss. To date, there have been four blade separations--three from fatigue cracks that initiated in the taper bore. The first blade separation (Inter-Canadien) resulted in RGB and propeller separation, and the assembly fell to earth. During the second blade separation (Nordeste), the RGB and propeller assembly remained in place. During the third separation (the Luxair accident), in which a fracture occurred in the blade shank area, the RGB and propeller assembly again fell from the airplane. During the fourth blade failure (this accident), the RGB rotated out of position, and resulted in degraded aerodynamic performance and a fatal accident.

Although in two of the occurrences, the RGB and propeller fell clear and did not seriously compromise the airplane or degrade its performance, all of the occurrences clearly placed the airplane and its occupants at potential serious risk. On four occasions, stresses on blades with flaws (corrosion pits or mechanical damage) have produced a blade separation even though the propeller was certificated based on the assumption of an unlimited life. Because the current regulations do not require that an airframe survive if a blade breaks, and because Embraer has determined that the EMB-120 cannot survive the loss of a mid-blade or full-blade segment, minimizing the possibility of a propeller blade separation is imperative. To prevent future failures, it is essential that stress risers in the form of corrosion or mechanical damage are not permitted to occur on any propeller blade.

The Safety Board concurs that the taper bore repair procedure specified in the March 1996 Service Bulletins (and required by ADs) should have restored the surface of the taper bore of all existing propellers to a nearly new condition. Also, because Hamilton Standard has prohibited the use of the mechanical lead-removal tools during routine blade balancing, the likelihood of future inadvertent mechanical damage has been greatly reduced.

However, while the terminating taper bore repair procedure should detect and eliminate any chlorine-induced corrosion or mechanical damage, the Safety Board is concerned that exposure to small amounts of moisture or other atmospheric elements during routine maintenance, the recurring inspection procedure set forth in the CMM, periods of low utilization, or long-term storage may allow atmospheric-induced corrosion to begin in the taper bore. The Safety Board is aware of reports of corrosion and cracking in the taper bores of P-3 and C-130 propellers associated with long-term storage. Because of this, the Safety Board concludes that despite all the actions taken by Hamilton Standard and the FAA to date, there is a continuing potential for corrosion to develop in taper bores of the affected Hamilton Standard propeller blades. Therefore, the Safety Board believes that the FAA should require that Hamilton Standard consider long-term, atmospheric-induced corrosion effects and amend the CMM inspection procedure to reflect an appropriate interval that will detect any corrosion within the taper bore.

2.6 FAA Oversight

2.6.1 Role of Designated Engineering Representative and FAA Certifying Engineer

As discussed in Section 1.16.3, Hamilton Standard extended the applicability of the PS960A blending repair beyond its original purpose (blending of mechanical damage) to also allow blending of shotpeen impressions to remove ultrasonic indications without informing or involving its DER or the FAA (through its Certifying Engineer in the Engine and Propeller Directorate). Hamilton Standard was aware that the FAA Certifying Engineer had earlier determined that repair procedures to the taper bore would require direct FAA approval. Consistent with this determination, both the DER (who served as a liaison to the FAA) and the Certifying Engineer were involved in developing the initial ultrasonic inspection procedures later set forth in ASB 14RF-0-61-A66 and the PS960A repair procedure. If Hamilton Standard had consulted with the DER and the FAA about the proposed extension and the reason for it (ultrasonic indications in blades without any visible damage), it might have prompted the FAA to reconsider whether the inspection and repair processes then being used were adequate to identify blades at risk for cracking.

Even though the extension of PS960A to allow blending of shotpeen impressions might have been approved by the FAA, if approval had been requested, Hamilton Standard's failure to seek such approval nonetheless played a role in creating the confusion that led to the misapplication of PS960A. The FAA's approval would likely have been documented in a fashion similar to its approval of PS960 and PS960A, clearly specifying the limits of the approved extension. In contrast, as discussed in Section 2.2.1.1, Hamilton Standard's attempt to internally document the extension was confusing and led to the misapplication of the repair to unshotpeened taper bores with unexplained ultrasonic indications.

Accordingly, the Safety Board concludes that Hamilton Standard's failure to seek FAA approval of the extension of PS960A blending repair hindered the FAA's ability to oversee Hamilton Standard's handling of the taper bore crack and corrosion problem, and led to an inadequate documentation of the extension that caused confusion and misapplication of the repair. Although the DER stated that this lapse in communication was atypical, the Safety Board is concerned--especially in light of the inadequate manner in which Hamilton Standard communicated the information to its managers and technicians--that it may represent a deficiency in Hamilton Standard's corporate communication. Specifically, it suggests that Hamilton Standard placed insufficient emphasis on proper communication of vital safety information. Accordingly, the Safety Board believes that the FAA should require Hamilton Standard to review and, if necessary, revise its policies and procedures regarding 1) internal communication and documentation of engineering decisions, and 2) involvement of the DER and FAA, and to ensure that there is proper communication, both internally and with the FAA, regarding all significant engineering decisions.

2.7 Weather

The flight was operating in accordance with an IFR flight plan and was climbing above overcast clouds at the initiation of the accident sequence. A weather observation taken at CTJ, approximately 4 miles from the crash site, reported an 800-foot overcast cloud ceiling just after the accident. However, weather conditions appropriate for visual flight below the clouds were reported at several airports near the accident site.

From the flightcrew's requests to ATC for vectors to the airfield, it is apparent that the cloud ceiling affected the flightcrew's ability to visually acquire a suitable landing site during the descent for a forced landing. In the latter portion of the descent, after descending below the overcast cloud ceiling, the airplane's height above the terrain would have limited the view of the flightcrew to just the immediate area. The airplane impacted the ground in a left-wing-down attitude, probably because the flightcrew was attempting to complete a turn to properly align themselves for the forced landing. If the overcast cloud ceiling had been higher, the crew would have had more time to align the airplane and level the wings before the impact. Consequently, the Safety Board concludes that the cloud ceiling precluded the flightcrew from being able to see the ground and thus to make a more successful forced landing, a situation that contributed to the severity of the accident.

2.8 Air Traffic Control Services

All FAA ATC personnel were trained, certificated, and qualified for their duties. There were no apparent physiological or behavioral impairments or disabilities that would have detracted from their ability to provide the expected air traffic services. Following the declaration of the emergency by the flightcrew and their continuing description of their difficulties, the controllers provided appropriate assistance to the crew.

The Atlanta Center controller did not issue the CTJ AWOS frequency. Although FAA ATC procedures[70] require that "both center and approach controllers shall provide current approach information to aircraft destined to airports for which they provide approach control services," in this case, the Atlanta Center controller was not responsible for approaches into CTJ and was not in the best position to have provided this information.

The closest weather report immediately available to the approach controller was the ATL Airport observation, the flight's departure point. There was no controller assigned to the "assist" position and although the manager and supervisor were nearby, they became occupied with coordinating and monitoring activities supporting the flight and did not attempt to retrieve the CTJ AWOS weather information by telephone. During the 90 seconds that the approach controller was in radio communication with the flight, the controller issued a vector toward the runway, the localizer frequency, confirmed the flight was in visual conditions and issued a vector for the visual approach. Therefore, the Safety Board concludes that, although the Atlanta approach controller did not issue the AWOS frequency or provide weather information, the controller performed higher priority tasks and, because the flight had to land at the nearest airport regardless of the weather, the failure to provide the CTJ weather information to the flightcrew was not a factor in this accident.

The Safety Board examined the performance of both the center and the approach controllers in assisting the accident flight. Once the flightcrew declared the emergency, Atlanta Center immediately issued instructions to permit the flight to return to ATL. Because of the location of the aircraft within the sector, the radar controller and manual assist controller coordinated with

[70]FAA Order 7110.65, "Air Traffic Control," Chapter 4, "IFR," Section 7, "Arrival Procedures," paragraph 4-7-13, "Approach Information," applies.

surrounding sectors; the center controller attempted to assist the accident flightcrew by providing vectors and airport information. However, because of the degraded flight performance of the aircraft, the flightcrew was not able to effect a timely response to the controller's instructions. When the flightcrew requested information normally available from the approach controller, such as runway heading and airport surface condition, the center controller instructed the flightcrew to contact the approach control facility. FAA ATC procedures[71] state in part, "If you are in communication with an aircraft in distress, handle the emergency and coordinate and direct the activities of assisting facilities. Transfer this responsibility to another facility only when you feel better handling of the emergency will result."

The flightcrew would have been able to advise the center controller that they preferred to remain on the current frequency because of the emergency, and the center controller may have been able to coordinate alternate procedures. Also, in retrospect, the Atlanta Center controller could have made an earlier handoff if he had been informed by the flightcrew of, or if he had perceived the full extent of, the performance degradation to the accident airplane. However, the Safety Board concludes that the timing of the handoff to Atlanta approach control by the Atlanta Center controller was not a factor in the accident.

The Safety Board is concerned, however, about the failure of ATC controllers to notify CFR services once the controllers were aware of the emergency situation. At 1644:25, the flightcrew of ASE 529 notified the Atlanta Center air traffic controllers that they had experienced an engine failure and declared an emergency. Two minutes later, the flightcrew advised that they needed to "land quick" and requested the controller to "roll the trucks and everything for us." The controller then advised the flightcrew that CTJ was the closest airport and directed the aircraft to CTJ. Although ATC was aware of the emergency situation and destination airport, ATC did not notify the fire and emergency services covering CTJ, the Carroll County Fire Department, of the incoming aircraft.

Atlanta Center should have immediately advised the appropriate CFR service or instructed Atlanta approach of the pilot's request so that they could have made timely airport emergency services notification. The accident had already

[71]FAA Order 7110.65, Chapter 10, "Emergencies," Section 1, "General," paragraph 10-1-4, "Responsibility," applies.

occurred when the Atlanta approach controller made the call to the Carroll County Sheriff, and it had already been reported by a citizen on 911. The Safety Board concludes that if the Atlanta Center had placed a call for emergency services as soon as the pilot requested, which was 10 minutes before the accident, personnel would have responded sooner, and the rescue efforts might have been more timely and effective. Therefore, the Safety Board believes that the FAA should include an article in the Air Traffic Bulletin and provide a mandatory formal briefing to all air traffic controllers regarding the necessity and importance of notifying crash, fire and rescue personnel upon a pilot's request for emergency assistance. Ensure that air route traffic control center (ARTCC) controllers are aware that such a request may require them to notify local emergency personnel.

2.9 Survival Factors Aspects

The Safety Board commends the exemplary manner in which the flight attendant briefed the passengers and handled the emergency. According to passengers, immediately following the loss of the propeller blade, the flight attendant checked with each passenger individually to make sure that they all understood how to assume the brace position, and she yelled instructions to the passengers up until the time of impact. After the crash, although she was seriously injured, she continued to assist the passengers by moving them away from the airplane and extinguishing flames on at least one passenger who was on fire.

2.9.1 Time Management During Emergencies

The Safety Board recognizes that the flightcrew in this accident was attempting to control the aircraft. However, the Safety Board is concerned that the flight attendant neither received nor sought information about the time remaining to prepare the cabin or to brace for impact. The CVR transcript revealed that the flightcrew informed her 7 minutes before impact that they had experienced an engine failure, that they had declared an emergency for return to ATL, and that they had advised her to brief the passengers. There were no further communications to the flight attendant. Specifically, the flight attendant was never told that the airplane would not be able to make ATL, and would instead be making an off-airport crash landing. The flight attendant stated that while preparing the cabin and passengers, she saw the tree tops from a cabin window. She immediately returned to her jump seat and shouted her commands. A passenger commented that the flight attendant was barely in the brace position when the impact occurred.

The Safety Board is concerned that the flight attendant and the flightcrew did not discuss a brace signal and the time available to prepare the cabin, and that the flightcrew did not announce a brace command on the public address system. Further, if the flight attendant had not had sufficient time to fasten her safety belt and shoulder harness, she might have received more serious or fatal injuries, and she might have been incapable of directing an evacuation.

The FAA has recognized that communication and coordination between cockpit crewmembers and flight attendants continue to challenge air carriers and the FAA. Advisory Circular (AC) 120-51B, "Crew Resource Management Training," suggests several methods of addressing this problem. Paragraph 15, Evolving Concepts of CRM: Extending Training Beyond the Cockpit, addresses specific subjects for joint training but does not specifically deal with the communication of critical information during an emergency.

The Safety Board's special investigation report on flight attendant training[72] describes another accident on page 28:

> The lead flight attendant in the DC-10 stated that she knew emergency procedures required her to determine the amount of time available to prepare the passengers and the cabin. However, she chose not to ask the flightcrew about the time. Additionally, the second item on the flight attendant checklist was "Determine Time," but none of the flight attendants followed this checklist procedure.

Although the FAA issued Air Carrier Operations Bulletin 1-91-11 in response to Safety Board Safety Recommendation A-90-173, which called for inspectors to reiterate the importance of time management in the preparation of the cabin in a planned emergency, the Safety Board concludes that this accident also illustrates that critical information regarding time available to prepare the aircraft for an emergency landing or impact is not being considered and communicated among flight and cabin crewmembers. Therefore, to improve the interactions between the cockpit and cabin crews, the Safety Board believes that the FAA should amend AC 120-51B to include guidance regarding the communication of

[72]See Special Investigation Report—"Flight Attendant Training and Performance During Emergency Situations" (NTSB/SIR-92/02)

time management information among flight and cabin crewmembers during an emergency.

2.9.2 Crash Axes

The captain and first officer were trapped in the cockpit by fire that had ignited on the cabin side of the cockpit door. When the first officer found it impossible to open his cockpit sliding window, he unsuccessfully attempted to chop a hole in the hardened Plexiglas side window using the airplane crash ax. It was apparently intended for use as a woodworking tool because it consisted of a blade and nail puller attached to a wooden handle. Given the resilient composition of the cockpit window material, it was difficult to make a hole in the window panel; however, if the ax had been equipped with a pry bar rather than a nail puller, the first officer might have been successful in wedging the pry bar between the window and the track or frame and prying or forcing the window open. Although regulations exist that require most passenger-carrying aircraft to be equipped with a crash ax,[73] there is no FAA or other civil technical standard regarding the design and use of crash axes. This accident demonstrates the importance of an adequate crash ax design.

The crash ax carried aboard military transport aircraft conforms to a special design. Large commercial transport airplanes manufactured in the United States are equipped with crash axes of similar design. Additionally, firefighter axes that have a wedge and pry bar tool features are in use by airport rescue and fire fighting personnel and municipal emergency medical technicians. The Safety Board concludes that there should be standards governing the design of crash axes required to be carried aboard passenger-carrying aircraft. Therefore, the Safety Board believes that the FAA should evaluate the necessary functions of the aircraft crash ax, and provide a technical standard order or other specification for a device that serves the functional requirements of such tools carried aboard aircraft.

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[73]See 14 CFR 91.513(e), 135.177(a)(2), and 121.309(e).

3. CONCLUSIONS

3.1 Findings

1. The flightcrew was trained, certificated and qualified to conduct the flight, and the flight was conducted in accordance with applicable Federal Aviation Regulations and company requirements.

2. The flightcrew was in good health and held the proper FAA medical certificates. There was no evidence that the performance of any crewmember was impaired by alcohol, drugs, or fatigue.

3. ASA maintained the airplane in accordance with applicable Federal Aviation Regulations and company Operations Specifications.

4. After the propeller blade separation, the combination of the resulting loss of left engine thrust, increased drag from a deformed engine nacelle and the three blades retained in the propeller hub and added frontal drag from external sheet metal damage degraded airplane performance preventing the flightcrew from arresting the airplane's descent or making rapid changes in its direction of flight making a forced landing necessary.

5. One of the four blades from the left engine propeller separated in flight because a fatigue crack that originated from multiple corrosion pits in the taper bore surface of the blade spar propagated toward the outside of the blade, around both sides of the taper bore, then reached critical size.

6. Because of the severely degraded aircraft performance following the propeller blade separation, the flightcrew's actions were reasonable and appropriate during their attempts to control and maneuver the airplane throughout the accident sequence, and they were not a factor in this accident.

7. Hamilton Standard's engineering decision to use the PS960A blending repair to remove ultrasonic indications caused by a shotpeened taper bore surface was technically reasonable.

8. The manner in which the unapproved extension of PS960A was documented and communicated within Hamilton Standard, and the lack of training on the extension, created confusion and led to misapplication of the blending repair to unshotpeened blades with unexplained ultrasonic indications, allowing the accident blade to be placed back into service with an existing crack.

9. The sanding marks left by the PS960A blending repair did not contribute to the initiation of the fatigue crack in the accident blade.

10. The failure to restore the taper bore surface to the original surface finish, as required by PS960A, was a factor that caused the reduction of the ultrasonic indication that allowed the blade to pass the final ultrasonic inspection and to be returned to service.

11. The borescope inspection procedure developed and used by Hamilton Standard in June 1994 to inspect returned blades that had rejectable ultrasonic indications for evidence of cracks, pits, and corrosion was inadequate and ineffective.

12. The introductory technical training to prepare the new, inexperienced workforce at Hamilton Standard's Rock Hill Customer Service Center might have been adequate; but the training initially given to technicians, who inspected blades that were returned to Rock Hill as a result of on-wing ultrasonic inspections, including the accident blade, was inadequate to ensure proficiency in the detection of taper bore corrosion or associated cracks.

13. If Hamilton Standard had recommended, and the FAA had required, repetitive ultrasonic inspections for all propellers after shortcomings were recognized and improvements were

made in the inspection process (particularly those that had already been inspected), the crack in the accident blade would most likely have been detected.

14. A combination of 2P resonance and GAG cycle stresses initiated the crack from the corrosion pits in the ASA blade and caused the crack to propagate to failure under normal operating conditions.

15. Advisory Circular AC 20-66 does not provide guidelines for adequate margin between a propeller blade's natural frequencies and its potentially coincident excitation frequencies over the life of the blade.

16. There is a potential for corrosion to develop in taper bores of the affected Hamilton Standard propeller blades.

17. The cloud ceiling precluded the flightcrew from being able to see the ground and thus to make a more successful forced landing.

18. Hamilton Standard's failure to seek FAA approval of the extension of PS960A blending repair hindered the FAA's ability to oversee Hamilton Standard's handling of the taper bore crack and corrosion problem, and led to an inadequate documentation of the extension that caused confusion and misapplication of the repair.

19. The timing of the handoff to Atlanta approach control by the Atlanta Center controller was not a factor in the accident.

20. Although the Atlanta approach controller did not issue the AWOS frequency or provide weather information, the controller performed higher priority tasks; and because the flight had to land at the nearest airport regardless of the weather, the failure to provide the CTJ weather information to the flightcrew was not a factor in this accident.

21. If the Atlanta Center had placed a call for emergency services as soon as the pilot requested, which was 10 minutes before the accident, personnel would have responded sooner, and the rescue efforts might have been more timely and therefore more effective.

22. This accident illustrates that critical information regarding time available to prepare the aircraft for an emergency landing or impact is not being considered and communicated among flight and cabin crewmembers.

23. There should be standards governing the design of crash axes required to be carried aboard passenger-carrying aircraft.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight fatigue fracture and separation of a propeller blade resulting in distortion of the left engine nacelle, causing excessive drag, loss of wing lift, and reduced directional control of the airplane. The fracture was caused by a fatigue crack from multiple corrosion pits that were not discovered by Hamilton Standard because of inadequate and ineffective corporate inspection and repair techniques, training, documentation, and communications.

Contributing to the accident was Hamilton Standard's and FAA's failure to require recurrent on-wing ultrasonic inspections for the affected propellers.

Contributing to the severity of the accident was the overcast cloud ceiling at the accident site.

4. RECOMMENDATIONS

As a result of the investigation of this accident, the National Transportation Safety Board makes the following recommendations:

--to the Federal Aviation Administration:

Require Hamilton Standard to review and evaluate the adequacy of its tools, training, and procedures for performing propeller blend repairs, and ensure that those blend repairs are being performed properly. (A-96-142)

Review the need to require inspection ("buy back") after the completion of work that is performed by uncertificated mechanics at Part 145 repair stations to ensure the satisfactory completion of the assigned tasks. (A-96-143)

Revise Advisory Circular 20-66 to include the vibratory testing of composite propeller blades that have been previously operated for a substantial number of service hours, and composite blades that have been altered to the limits set forth in FAA-approved repair manuals to determine the expected effects of age on propeller vibration and provide guidelines for rpm margin between a propeller blade's natural frequencies and the excitation frequencies associated with propeller operation. (A-96-144)

Require that Hamilton Standard consider long-term, atmospheric-induced corrosion effects and amend the Component Maintenance Manual (CMM) inspection procedure to reflect an appropriate interval that will detect any corrosion within the taper bore. (A-96-145)

Require Hamilton Standard to review and, if necessary, revise its policies and procedures regarding 1) internal communication and documentation of engineering decisions, and 2) involvement of the Designated Engineering Representative (DER) and FAA, and to ensure that there is proper communication, both internally and with the FAA, regarding all significant engineering decisions. (A-96-146)

Include an article in the Air Traffic Bulletin and provide a mandatory formal briefing to all air traffic controllers regarding the necessity and importance of notifying crash, fire and rescue personnel upon a pilot's request for emergency assistance. Ensure that air route traffic control center (ARTCC) controllers are aware that such a request may require them to notify local emergency personnel. (A-96-147)

Amend Advisory Circular 120-51B (Crew Resource Management Training) to include guidance regarding the communication of time management information among flight and cabin crewmembers during an emergency. (A-96-148)

Evaluate the necessary functions of the aircraft crash ax, and provide a technical standard order or other specification for a device that serves the functional requirements of such tools carried aboard aircraft. (A-96-149)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

James E. Hall
Chairman

Robert T. Francis II
Vice Chairman

John Hammerschmidt
Member

John J. Goglia
Member

George W. Black
Member

November 26, 1996

5. APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. Investigation

The Safety Board was notified of the accident by the FAA Communication Center about 1330 on August 21, 1995. An investigator was immediately dispatched to the crash site from the Southeast Field Office in Atlanta, and a full go-team was sent from Safety Board Headquarters in Washington, D.C. The following investigative groups were formed: Operations, Structures, Systems, Powerplants, Maintenance Records, Air Traffic Control, Weather, Aircraft Performance, Survival Factors, Cockpit Voice Recorder, and Flight Data Recorder. Member John Hammerschmidt accompanied the team to Carrollton, Georgia. A Metallurgy Group was later formed at the Safety Board's Materials Laboratory to study evidence of the failed propeller.

In accordance with the provisions of the International Civil Aviation Organization's International Standards and Recommended Practices, Annex 13, Aircraft Accident and Incident Investigation, the Center for the Investigation and Prevention of Accidents, Brazil, (state of manufacture of the airplane) and the Transportation Safety Board of Canada, (state of manufacture of the engines) were notified of the accident, and each state sent an Accredited Representative, with advisers to participate in the investigation. A draft of the final accident report was provided to each Accredited Representative for comment. Their comments have been incorporated into the final report.

Parties to the investigation included the Federal Aviation Administration, Atlantic Southeast Airlines, Empresa Brasileira de Aeronautica S. A. (Embraer Aircraft Corporation), the Pratt and Whitney, Canada, Division of United Technologies Corporation, the Hamilton Standard Division of United Technologies Corporation, the Air Line Pilots Association, the Association of Flight Attendants, and the National Air Traffic Controller's Association.

2. Public Hearing

No public hearing was conducted for this investigation.

APPENDIX B

COCKPIT VOICE RECORDER TRANSCRIPT

LEGEND

HOT	Crewmember hot microphone voice or sound source
HOT-M	Aircraft mechanical voice heard on all channels
RDO	Radio transmission from accident aircraft
CAM	Cockpit area microphone voice or sound source
INT	Transmissions over aircraft interphone system
TWRA	Radio transmission from Atlanta control tower
ATLD	Radio transmission from Atlanta departure control
CTR	Radio transmission from Atlanta center
ATLA	Radio transmission from Atlanta approach control
UNK	Radio transmission received from unidentified aircraft
PA	Transmission made over aircraft public address system
-B	Sounds heard through both pilot's hot microphone systems
-1	Voice identified as Pilot-in-Command (PIC)
-2	Voice identified as Co-Pilot
-3	Voice identified as female flight attendant
-?	Voice unidentified
*	Unintelligible word
@	Non pertinent word
#	Expletive
%	Break in continuity
( )	Questionable insertion
[ ]	Editorial insertion
....	Pause

Note: Times are expressed in eastern daylight time (EDT).
Times shown in brackets ( ) are computer reference times measured from the beginning of the recording.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
START of RECORDING			
START of TRANSCRIPT			
		1222:39 **TWRA**	{00:22} AC five twenty nine, turn left heading zero six zero runway eight right. cleared for takeoff.
		1222:45 **RDO-2**	{00:28} zero six zero eight right, cleared for takeoff, AC five twenty nine.
1222:48 **HOT-1**	{00:31} takeoff check, below the line, I got your lights.		
1222:52 **HOT-2**	{00:35} condition levers? max.		
1222:52 **HOT-2**	{00:35} bleeds and packs? standard.		
1222:53 **HOT-2**	{00:36} external lights? on.		
1222:54 **HOT-2**	{00:37} below the line's complete.		
1222:55 **HOT-1**	{00:38} alright.		
1223:00 **CAM**	{00:43} [sound of increase in rpm similar to takeoff power being applied]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1223:19 **HOT-2**	{01:02} power set, auto-feather's armed, panel's clear, airspeed's alive.		
1223:24 **HOT-2**	{01:07} V 1.		
1223:25 **HOT-2**	{01:08} V r.		
1223:29 **HOT-2**	{01:12} pos' rate.		
1223:30 **HOT-1**	{01:13} gear up.		
1223:37 **HOT-1**	{01:20} wipers off.		
		1223:46 **TWRA**	{01:29} AC five twenty nine, contact departure. fly heading zero six zero now. we'll see ya.
		1223:49 **RDO-2**	{01:32} zero six zero switching, see ya.
1223:51 **HOT-B**	{01:34} [single beep similar to radio frequency change]		
		1224:00 **RDO-2**	{01:43} Atlanta departure, AC five twenty nine's with you, leaving one point eight for four, heading sixty.
		1224:07 **ATLD**	{01:50} AC five twenty nine, Atlanta departure roger, radar contact. maintain one zero thousand.
		1224:13 **RDO-2**	{01:56} one zero thousand, AC five twenty nine.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1224:17 **HOT-2**	{02:00} **.		
1224:17 **HOT-1**	{02:00} ten.		
1224:31 **HOT-1**	{02:14} climb power, * takeoff.		
1225:04 **HOT-2**	{02:47} gear's up, flaps are up, pressure's checked, climb power set, bleeds and packs auto, APU's off, auto-feather off, flight attendant notified ****.		
1225:11 **HOT-1**	{02:54} thank you.		
		1225:26 **RDO-2**	{03:09} five twenty nine's up, at twenty four.
1225:27 **HOT-B**	{03:10} [single beep similar to radio frequency change]		
1225:41 **HOT-1**	{03:24} is this the s*, this the ## that uh, kept doin' that to us? on take-off?		
1225:54 **HOT-2**	{03:37} yeah this is the one, that these were loose.		
		1225:57 **ATLD**	{03:40} AC five twenty nine turn left heading three six zero.
		1225:59 **RDO-2**	{03:42} left three sixty, AC five twenty nine.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1226:03 **HOT-1**	{03:46} no he didn't, didn't know whether, the high pack was causing the problem or.		
		1227:29 **ATLD**	{05:12} AC five twenty nine turn left heading two seven zero.
		1227:33 **RDO-2**	{05:16} left * two seven zero, AC five twenty nine.
1227:41 **HOT-1**	{05:24} let's look at the radar there.		
1227:44 **HOT-2**	{05:27} just a bunch of scattered stuff *.		
		1228:37 **ATLD**	{06:20} AC five twenty nine, maintain one one thousand.
		1228:40 **RDO-2**	{06:23} one one thousand, AC five twenty nine.
1228:42 **HOT-2**	{06:25} eleven.		
1228:43 **HOT-1**	{06:26} *		
1228:59 **HOT-1**	{06:42} stick it back in auto and see if it'll, work again.		
1229:35 **HOT-2**	{07:18} one more. (feels) alright.		
1230:05 **CAM**	{07:48} [sound of three beeps similar to altitude alert signal]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1231:33 **ATLD**	{09:16} AC five twenty nine, turn left heading two five zero.
		1231:35 **RDO-2**	{09:18} two five zero, AC five twenty nine.
		1232:02 **ATLD**	{09:45} AC five twenty nine, climb and maintain one two thousand.
		1232:06 **RDO-2**	{09:49} one two thousand, AC five twenty nine.
1232:08 **HOT-2**	{09:51} twelve.		
1232:09 **HOT-1**	{09:52} tell Robin it just be a couple of minutes it'll smooth out.		
1232:18 **CAM**	{10:01} [sound of two chimes similar to flight attendant call chime]		
1232:19 **INT-3**	{10:02} hello.		
1232:20 **INT-2**	{10:03} hey Robin.		
1232:21 **INT-3**	{10:04} hi.		
1232:22 **INT-2**	{10:05} it'll be a just a couple more minutes like this, it'll smooth out.		
1232:24 **INT-3**	{10:07} uuh, couple more minutes and then I can get up?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1232:25 **INT-2**	{10:08} yes ma'am.		
1232:26 **INT-3**	{10:09} alright, thank you.		
1232:27 **INT-2**	{10:10} see ya.		
1232:40 **HOT-2**	{10:23} four more.		
1232:41 **HOT-B**	{10:24} [three beeps similar to altitude alert signal]		
		1234:52 **ATLD**	{12:35} AC five twenty nine, climb and maintain one three thousand.
		1234:55 **RDO-2**	{12:38} one three thousand, AC five twenty nine.
1234:57 **HOT-1**	{12:40} thirteen.		
1235:01 **HOT-1**	{12:44} props ninety.		
1235:02 **HOT-?**	{12:45} ***.		
1235:07 **HOT-1**	{12:50} [mechanical vibrating sound starts similar to boom microphone vibrating against cockpit surface]		
1235:15 **CAM**	{12:58} [sound similar to propellers decreasing in RPM]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1235:31 **HOT-B**	{13:14} [sound of three beeps similar to altitude alert]		
1235:34 **CAM-2**	{13:17} four more.		
1235:42 **CAM-1**	{13:25} ** lights out *****.		
1235:54 **PA-2**	{13:37} ladies and gentlemen, good afternoon, welcome aboard Atlantic Southeast Airlines flight seventy five twenty nine, service to Gulfport. we're passing through thirteen thousand feet, captain has turned off the fasten seat belt sign. you are free to move about the cabin as you wish. however if you're in your seats, we ask you do so with your belts fastened loosely around you, just in case we encounter any turbulence enroute. Gulfport on the hour is calling for partly cloudy skies, temperature of eighty degrees, and winds ten miles an hour out of the northeast. there's anything we can do to make your flight more enjoyable, please do not hesitate to call upon us. and thank you for flying with ASA.		
		1235:58 **ATLD**	{13:41} AC five twenty nine maintain one four thousand. contact Atlanta center on one three four point niner five.
		1236:05 **RDO-1**	{13:48} one three four ninety five and fourteen thousand, AC uh, five twenty nine.
		1236:10 **ATLD**	{13:53} good day sir, it's thirty four ninety five.
		1236:13 **RDO-1**	{13:56} thirty four ninety five.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1236:20 **HOT-B**	{14:03} [single beep similar to radio frequency change]		
		1236:25 **RDO-1**	{14:08} center, AC five twenty nine is out of thirteen for fourteen.
		1236:28 **CTR**	{14:11} AC five twenty nine, Atlanta center roger. I'll have a higher altitude for you in just a moment.
		1236:32 **RDO-1**	{14:15} five twenty nine.
1236:35 **CAM-2**	{14:18} I'm back.		
1236:36 **CAM-1**	{14:19} alright, up to fourteen and, talking to center, expectin' higher in a while.		
1236:42 **CAM-2**	{14:25} OK.		
1237:10 **HOT-B**	{14:53} [sound of three beeps similar altitude alert signal]		
1237:14 **CAM-2**	{14:57} ***.		
1237:20 **CAM-1**	{15:03} yeah, I guess. I'm not sure what the hell is this?		
		1237:32 **CTR**	{15:15} AC five twenty nine, climb and maintain one five thousand.
		1237:34 **RDO-2**	{15:17} one five thousand, AC five twenty nine.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1237:38 **CAM-2**	{15:21} *** fifteen ***.		
1237:51 **CAM-1**	{15:34} **** I can't get to.		
1238:10 **CAM-1**	{15:53} something underneath the #.		
1238:17 **CAM-2**	{16:00} it'll drive you nuts.		
1238:18 **CAM-1**	{16:01} it will drive you nuts.		
1238:29 **HOT-B**	{16:12} [three beeps similar to altitude alert]		
1238:32 **CAM-2**	{16:15} four more.		
		1239:24 **CTR**	{17:07} AC five twenty nine, climb and maintain flight level one niner zero.
		1239:27 **RDO-2**	{17:10} one niner zero, AC five twenty nine.
1239:30 **CAM**	{17:13} [single beep similar to altitude alert]		
1241:32 **CAM-1**	{19:15} **long* duct tape ** around here *****.		
		1241:57 **CTR**	{19:40} AC five twenty nine, climb and maintain flight level two zero zero.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1242:01 **RDO-2**	{19:44} two zero zero, AC five twenty nine.
1242:04 **CAM-2**	{19:47} twenty.		
		1242:40 **CTR**	{20:23} AC five twenty nine, climb and maintain flight level two four zero.
		1242:44 **RDO-2**	{20:27} two four zero, AC five twenty nine.
1242:46 **CAM**	{20:29} [sound similar to dialing altitude alerter]		
1242:50 **CAM-2**	{20:33} twenty four.		
1242:51 **CAM-1**	{20:34} twenty four.		
1243:25 **CAM**	{21:08} [sound of several thuds]		
1243:26 **CAM-1**	{21:09} ****.		
1243:28 **CAM**	{21:11} [three chimes similar master warning] auto-pilot, engine control, oil [and continues to repeat]		
1243:29 **CAM-?**	{21:12} *.		
1243:32 **CAM-2**	{21:15} pack off.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
1243:34 **CAM-1**	{21:17} *.		
1243:38 **CAM-1**	{21:21} we got a left engine out. left power lever. flight idle.		
1243:45 **CAM**	{21:28} [shaking sound starts and continues for thirty three seconds]		
1243:46 **CAM-1**	{21:29} left condition lever. left condition lever.		
1243:48 **CAM-2**	{21:31} yeah.		
1243:49 **CAM-1**	{21:32} feather.		
1243:51 **HOT-B**	{21:34} [series of rapid beeps for one second similar to engine fire warning]		
1243:54 **CAM-1**	{21:37} yeah we're feathered. left condition lever, fuel shut-off.		
1243:59 **CAM-1**	{21:42} I need some help here.		
1244:02 **CAM**	{21:45} [mechanical voice messages for engine control and oil cease. chimes and auto-pilot warning continues]		
1244:03 **CAM-2**	{21:46} OK.		
1244:03 **CAM-1**	{21:46} I need some help on this.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1244:05 **CAM-?**	{21:48} (you said it's) feathered?		
1244:06 **CAM-1**	{21:49} uh,		
1244:07 **CAM-2**	{21:50} it did feather.		
1244:07 **CAM-1**	{21:50} it's feathered.		
1244:09 **CAM-2**	{21:52} OK.		
1244:09 **CAM**	{21:52} [master warning chimes and voice warning continues]		
1244:10 **CAM-1**	{21:53} what the hell's going on with this thing.		
1244:13 **CAM-2**	{21:56} I don't know... got this detector inop.		
1244:16 **CAM-1**	{21:59} OK ***.		
1244:18 **CAM-?**	{22:01} OK, let's put our head sets on.		
1244:20 **CAM-1**	{22:03} I can't hold this thing..		
1244:23 **CAM-1**	{22:06} help me hold it.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1244:24 **HOT-2**	{22:07} OK.		
1244:26 **CAM-1**	{22:09} alright comin' on headset.		
		1244:26 **RDO-2**	{22:09} Atlanta center. AC five twenty nine, declaring an emergency. we've had an engine failure. we're out of fourteen two at this time.
		1244:31 **CTR**	{22:14} AC five twenty nine, roger, left turn direct Atlanta.
1244:33 **HOT-1**	{22:16} # damn.		
		1244:34 **RDO-2**	{22:17} left turn direct Atlanta, AC five twenty nine.
1244:36 **HOT-?**	{22:19} [sound of heavy breathing]		
1244:41 **HOT-?**	{22:24} ** back **.		
1244:57 **HOT-?**	{22:40} [sound of squeal]		
1245:01 **CAM**	{22:44} [tone similar to master caution cancel button being activated. all warnings cease]		
1245:03 **HOT-1**	{22:46} alright turn your speaker off. oh, we got it. its.		
1245:07 **HOT-1**	{22:50} I pulled the power back.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1245:10 **CTR**	{22:53} AC five twenty nine, say altitude descending to.
		1245:12 **RDO-2**	{22:55} we're out of eleven six at this time. AC five twenty nine.
1245:17 **HOT-1**	{23:00} alright, it's, it's getting more controllable here ... the engine ..... let's watch our speed.		
1245:32 **HOT-1**	{23:15} alright, we're trimmed completely here.		
1245:38 **HOT-2**	{23:21} I'll tell Robin what's goin' on.		
1245:39 **HOT-1**	{23:22} yeh.		
1245:44 **HOT-B**	{23:27} [sound of two chimes similar to cabin call button being activated]		
1245:45 **INT-3**	{23:28} yes sir.		
1245:46 **INT-2**	{23:29} OK, we had an engine failure Robin. we declared an emergency, we're diverting back into Atlanta. go ahead and uh, brief the passengers. this will be an emergency landing back in.		
1245:55 **INT-3**	{23:38} alright. thank you.		
1245:56 **HOT-1**	{23:39} tell 'em we want ...		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1245:58 **CTR**	{23:41} AC five twenty nine, say altitude leaving.
		1246:01 **RDO-2**	{23:44} AC five twenty nine's out of ten point three at this time.
		1246:03 **CTR**	{23:46} AC five twenty nine roger, can you level off or do you need to keep descending?
1246:09 **HOT-1**	{23:52} we ca.. we're gonna need to keep con.. descending. we need a airport quick.		
		1246:13 **RDO-2**	{23:56} OK, we uh, we're going to need to keep descending. we need an airport quick and uh, roll the trucks and everything for us.
		1246:20 **CTR**	{24:03} AC five twenty nine, West Georgia, the regional airport is at your .. ten o'clock position and about ten miles.
		1246:28 **RDO-2**	{24:11} understand ten o'clock and ten miles, AC five twenty nine.
		1246:30 **CTR**	{24:13} 's correct.
1246:36 **HOT-1**	{24:19} (* give me) [whispered]		
1246:38 **HOT-1**	{24:21} let's get out the uh .... engine failure check list, please.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1246:47 **HOT-2**	{24:30} OK, I'll do it manually here.		
1246:55 **HOT-2**	{24:38} OK, engine failure in flight.		
		1246:57 **CTR**	{24:40} AC five twenty nine, say heading.
		1246:59 **RDO-2**	{24:42} turnin' to about uh, three ten right now.
1247:01 **HOT-2**	{24:44} power level's, flight idle.		
		1247:03 **CTR**	{24:46} AC five twenty nine, roger. you need to be on about a zero three zero heading for West Georgia Regional, sir.
		1247:07 **RDO-2**	{24:50} roger, we'll ("probly", or possibly,"try'ta") turn right. we're having uh, difficulty controlling right now.
1247:11 **HOT-2**	{24:54} OK, condition lever's, feather,		
1247:13 **HOT-1**	{24:56} alright.		
1247:14 **HOT-2**	{24:57} it did feather... Np's showing zero.		
1247:18 **HOT-1**	{25:01} 'K.		
1247:19 **HOT-2**	{25:02} OK.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1247:20 **CTR**	{25:03} AC five twenty nine, when you can, it's zero four zero.
		1247:22 **RDO-2**	{25:05} zero four zero, AC five twenty nine.
1247:25 **HOT-2**	{25:08} 'K, electric, yeah OK it did feather. there's no fire.		
1247:27 **HOT-1**	{25:10} alright.		
1247:28 **HOT-2**	{25:11} OK..		
1247:32 **HOT-2**	{25:15} main auxiliary generators of the failed engine off.		
1247:35 **HOT-1**	{25:18} 'K. I got that.		
1247:40 **HOT-2**	{25:23} 'K, APU .. if available, start. want me to start it?		
1247:45 **HOT-1**	{25:28} we gotta, bring this down, bring those. put the that off. bring the ice off...		
1247:54 **HOT-B**	{25:37} [sound of chime similar to master caution starts and repeats at six second intervals until the end of the recording]		
1247:56 **HOT-?**	{25:39} *.		
		1247:56 **CTR**	{25:39} AC five twenty nine uh, say your altitude now sir.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1247:59 **RDO-2**	{25:42} out of seven thousand, AC five twenty nine.
1248:00 **HOT-B**	{25:43} [sound of three chimes followed by voice message] trim fail. [warning starts and continues]		
1248:04 **HOT-1**	{25:47} good start.		
		1248:04 **CTR**	{25:47} AC five twenty nine, I missed that, I'm sorry.
		1248:06 **RDO-2**	{25:49} we're outta six point nine right now, AC five twenty nine.
		1248:09 **CTR**	{25:52} AC five twenty nine roger, West Georgia Regional, heading zero seven zero.
		1248:13 **RDO-2**	{25:56} zero seven zero, AC five twenty nine.
1248:20 **HOT-B**	{26:03} [sound of single beep]		
1248:33 **HOT-2**	{26:16} OK, it's up and running, Ed.		
1248:34 **HOT-1**	{26:17} alright, go ahead.		
		1248:35 **CTR**	{26:18} AC five twenty nine, West Georgia Regional is your closest airport. the other one's uh, Anniston and that's about thirty miles to your west, sir.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1248:40 **HOT-1**	{26:23} how long, how far West Georgia Reg ... what kind of a runway they got?		
		1248:44 **RDO-2**	{26:27} what kind of runway's West Georgia Regional got?
1248:54 **HOT-1**	{26:37} go ahead and finish the check list.		
		1248:58 **CTR**	{26:41} West Georgia Regional is uh, five say one six and three four and it's five thousand feet ....
1249:01 **HOT-2**	{26:44} OK, APU started. OK, prop sync, off. prop sync's comin' off.		
1249:03 **HOT-1**	{26:46} OK.		
1249:04 **HOT-2**	{26:47} fuel pumps failed engine. you want uh, max on this?		
1249:07 **HOT-1**	{26:50} go ahead, please.		
1249:08 **HOT-2**	{26:51} OK.		
1249:09 **CAM**	{26:52} [sound similar to propeller increasing in RPM]		
		1249:09 **CTR**	{26:52} ... and it is asphalt sir.
1249:11 **HOT-2**	{26:54} hydraulic pump, failed engine? as required. put it to the on position?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1249:15 **HOT-1**	{26:58} correct.		
1249:17 **HOT-2**	{27:00} 'K. engine bleed failed engine is closed and the pack is off.		
1249:19 **HOT-1**	{27:02} 'K.		
1249:26 **HOT-2**	{27:09} 'K, cross-bleed open.		
1249:29 **HOT-1**	{27:12} 'K.		
1249:32 **HOT-2**	{27:15} electrical load, below four hundred amps.		
1249:38 **HOT-1**	{27:21} it is. put the ice ba ... (well you) don't need to do that just leave that alone.		
1249:45 **HOT-1**	{27:28} alright, single engine check list please.		
		1249:48 **CTR**	{27:31} AC five twenty nine, I've lost your transponder. say altitude.
		1249:52 **RDO-2**	{27:35} we're out of four point five at this time.
		1249:54 **CTR**	{27:37} AC five twenty nine, I've got you now and the airport's at your, say say your heading now sir.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1249:59 **RDO-2**	{27:42} right now we're heading uh, zero eight zero.
		1250:01 **CTR**	{27:44} roger, you need about ten degrees left. should be twelve o'clock and about eight miles.
		1250:05 **RDO-2**	{27:48} ten left, twelve 'n eight miles and uh, do we got a, ILS to this runway?
		1250:10 **CTR**	{27:53} uh, I'll tell you what. let me put you on approach. he works that airport and he will be able to give you more information. contact Atlanta approach on one two one point zero, sir.
1250:15 **HOT-1**	{27:58} we can get in on a visual.		
		1250:17 **RDO-2**	{28:00} one more time on the freq..
		1250:20 **RDO-1**	{28:03} say again the frequency?
		1250:22 **CTR**	{28:05} Atlanta approach one two one point zero.
		1250:24 **RDO-2**	{28:07} twenty one zero, see ya.
		1250:26 **UNK-?**	{28:09} good luck guys.
		1250:27 **RDO-2**	{28:10} 'preciate it.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1250:28 **HOT-B**	{28:11} [single beep similar to radio frequency change]		
		1250:29 **RDO-2**	{28:12} Atlanta approach, AC five twenty nine's with you out of three point four.
1250:36 **HOT-1**	{28:19} engine's exploded. it's just hanging out there.		
		1250:43 **RDO-2**	{28:26} Atlanta approach, AC five twenty nine.
		1250:45 **ATLA**	{28:28} AC five twenty nine, Atlanta approach.
		1250:48 **RDO-2**	{28:31} yes sir, we're with you declaring an emergency.
		1250:49 **ATLA**	{28:32} AC five twenty nine, roger. expect localizer runway three four approach and uh, could you fly heading one eight zero uh no sorry, one six zero?
		1250:56 **RDO-2**	{28:39} yeah we can do that. give me the loc freq ...
		1250:59 **ATLA**	{28:42} localizer frequency, runway three four localizer frequency is uh, one one one point seven.
1251:05 **HOT-1**	{28:48} we can get in on a visual. just give us vectors.		
		1251:07 **RDO-2**	{28:50} one one one point seven ..... just give us vectors. we'll go the visual.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1251:17 **HOT-1**	{29:00} sing, single, single engine check list, please.		
1251:28 **HOT-2**	{29:11} where the # is it?		
		1251:29 **ATLA**	{29:12} AC five twenty nine, say altitude leaving.
		1251:31 **RDO-2**	{29:14} we're out of nineteen hundred at this time.
1251:33 **HOT-1**	{29:16} we're below the clouds. tell 'm ...		
		1251:35 **ATLA**	{29:18} you're out of nineteen hundred now?
		1251:36 **RDO-2**	{29:19} 'K we're uh, VFR at this time. give us a vector to the airport.
		1251:39 **ATLA**	{29:22} AC five twenty nine. turn left uh, fly heading zero four zero. bear, the uh, airport's at your about ten o'clock and six miles sir. radar contact lost this time.
		1251:47 **RDO-2**	{29:30} zero four zero, AC five twenty nine.
1252:07 **HOT-M**	{29:50} five hundred.		
1252:10 **HOT-M**	{29:53} too low gear. [starts and repeats]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
		1252:11 **ATLA**	{29:54} AC five twenty nine, if able, change to my frequency, one one eight point seven. the airport uh, in the vicinity of your ten o'clock at twelve o'clock and about four miles or so.
1252:20 **HOT-1**	{30:03} help me, help me hold it, help me hold, help me hold it.		
		1252:26 **ATLA**	{30:09} AC five twenty nine, change frequency, one one eight point seven if able.
1252:32 **HOT-B**	{30:15} too low gear [warning stops]		
1252:32 **HOT-B**	{30:15} [series of rapid beeps similar to aural stall warning]		
1252:32 **CAM**	{30:15} [vibrating sound similar to aircraft stick shaker starts and continues for four seconds]		
1252:36 **CAM**	{30:19} [vibrating sound similar to aircraft stick shaker starts again and continues to impact]		
1252:37 **HOT-2**	{30:20} Amy, I love you.		
1252:40 **HOT-B**	{30:23} landing gear.		
1252:41 **CAM-?**	{30:24} [sound of grunting]		
1252:45 **CAM**	{30:28} [sound of impact]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1252:46 **HOT-B**	{30:29} landing gear		
1252:46 **CAM**	{30:29} [sound of impact]		
1252:46 **END of RECORDING**	{30:29}		

END of TRANSCRIPT

APPENDIX C

FRACTURE SUMMARY *

Aircraft/ Blade Model	Operator	Fracture Location	Initiating Defect	TT Hrs.	TO Hrs.	Observations	Blade S/N
ATR42/ 14SF-5	InterCanadian	Taperbore	0.031" deep pit x 0.058" wide	12,038	4,748	Coarse banding 10,000-15,000	856922
EMB120/ 14RF-9	Nordeste	Taperbore	Band of pits .011-.015" deep x 0.160" wide	4,210	N/A	Oxidized beach mark; 0.032" deep x 0.160" wide	865093
EMB120/ 14RF-9	ASA	Taperbore	Pit (initial size unknown); .005" deep x 0.037" wide (at surface) 0.011 wide (subsurface) All dimensions after rework	14,664 **	2,399	Oxidized beach mark; 0.0487" deep x 0.0542" wide (at surface) 0.066" wide (subsurface)	861398

*Information provided by Hamilton Standard for a February 2, 1996, briefing to the Safety Board.

**The Safety Board's investigation revealed that the total time was 14,728 operating hours and 5,182 hours since overhaul.

APPENDIX D

EMB-120/14RF-9 STRESS RESURVEY *

Summary of Flight Test Results

1. The highest vibratory stress measured in flight was ±6000 psi and occurred at the 20-inch and the 26-inch stations during maneuvers outside the normal flight envelope.

2. Vibratory stresses measured on the left propeller were about 2% higher than those seen in the 1985 survey.

3. Vibratory stresses measured on the right propeller were about 8% higher than those seen in the 1985 survey.

4. The right propeller stresses were about 6% higher than the left.

5. Some small differences in stressing amongst the blades were observed. Generally, blade number four was the highest. Average relative levels for the other blades were: Blade no. 1 - 97%, Blade no. 2 - 95%, Blade no. 3 - 96%, Blade no. 5 - 100%. Also, there was a standard deviation of ±3% on these relationships.

6. The frequency of vibratory stressing for all the strain gages except the shank leading edge was primarily 1P. The shank leading edge gage was primarily 2P with 1P also present during high-stress operation. This is consistent with historical data.

7. The Vee gage was always low in magnitude indicating no significant torsional response. This was as expected.

8. The distribution of stress along the blade was seen to be slightly different than theoretical. The 20-inch station was sometimes higher than the 26-inch station. Analysis indicates that the 26-inch station should be the highest. Also, the reduction in stress going inboard from the peak is less than theoretical, see plot.

9. The trend of stress versus aircraft c.g. vertical acceleration compares favorably with previous data, see plots.

10. The stresses experienced at the extremes of yaw maneuvers were considerably lower than those seen in the previous tests.

*Information provided by Hamilton Standard for a February 2, 1996, briefing to the Safety Board.

Summary of Ground Test Results

1. The highest vibratory stresses of the entire test occurred during ground running in an adverse wind when the propeller speed passed through the 2P/1f critical. The peak stress reached ±18,600 psi at the 26-inch station of blade number four. The wind was from the rear quarter at approximately 28 knots.

2. The 2P/1f critical speed was found to exist at approximately 935 rpm, which is between the locations observed in the previous two tests (1983 and 1985), see plots.

3. The vibratory stressing that occurs under these conditions is almost completely 2P in frequency. Adjacent blades are out of phase such that the reactions of the four blades cancel within the hub. This is consistent with previous data.

4. Frequency analysis of the strain gage data showed poorly defined peaks in the vicinity of the expected natural frequency. This could be due to mis-tunning or other unknown reasons.

5. The Vee gage was always low in magnitude indicating no significant torsional response. This was as expected.

6. The distribution of stress along the blade was seen to be slightly different from previous experience, see plot.

7. The high stressing associated with the 2P/1f critical speed were only observed during adverse wind operation. Tests in mild headwinds showed very low levels of stress. Again this is as expected.

8. In addition to the high stresses seen during operation in the region of the 2P/1f critical speed, additional stress peaks were observed during transient conditions at speeds other than the critical. These peaks appear to happen immediately after a power lever movement, independent of the operating speed. They look exactly like a rapid excursion through the critical speed, 2P in frequency with adjacent blades out of phase, see examples.

Conclusions & Recommendations

The results of this stress survey are consistent with past experience.

Small differences from previous stress levels were observed. Also, differences were seen among the blades and between the left and right nacelles. These differences are not considered significant.

The highest vibratory stressing occurred during ground operation in adverse winds when the propeller speed was at or near 935 rpm (72% of take-off). This is due to the presence of a critical speed caused by the coincidence of the first flatwise blade mode and excitation due to the second harmonic of the rotational speed. During the worst of these conditions the vibratory stresses were more than triple the highest values measured in flight, including maneuvers. Operation in this speed range must be kept to an absolute minimum to avoid fatigue damage to the blades.